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EFFECTS OF MIXED-FIELD RADIATION ON LUBRICATING OILS

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F. A. HALEY

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ABSTRACT

Samples of three aircraft turbine lubricating oils were irradiated with the Ground Test Reactor at General Dynamics/ Fort Worth while being worked in a special Dynamic Test Loop; static (unworked) samples were included in each irradiation.

MIL-L-7808C was irradiated at three exposure levels ranging from 4.6×10^6 to 2.0×10^9 ergs/gm(C)-hr gammas and 6.1×10^9 to 3.3×10^{10} n/cm^2-sec ($E_n > 2.9$ Mev) neutrons; GTO-790 was irradiated at a gamma dose rate of 3.4×10^8 ergs/ gm(C)-hr and 8.3×10^9 n/cm^2-sec ($E_n > 2.9$ Mev) associated neutrons; MIL-L-9236B was irradiated at a gamma dose rate of 4.6×10^8 ergs/gm(C)-hr and 1.1×10^{10} n/cm^2-sec ($E_n > 2.9$ Mev) associated neutrons. Bulk-oil temperatures ranged from 275° to 300°F during irradiation.

The results of property and performance measurements made on samples withdrawn during each irradiation indicate that MIL-L-7808C is somewhat more sensitive to reactor radiation than GTO-790 or MIL-L-9236B, both of which exhibited a similar resistance to radiation. Some variations were also noted between worked and unworked samples of each oil.

REPORT SUMMARY

This report covers the testing of three aircraft turbine lubricating oils irradiated with the Ground Test Reactor at General Dynamics/Fort Worth during the 1958 to 1961 period. The oils, identified as MIL-L-7808C, GTO-790, and MIL-L-9236B, were selected for testing because they are representative of typical lubricants for three temperature ranges: -65°F to 300°F, -45°F to 350°F, and -65°F to 400°F, respectively.

Each oil was irradiated while operating in a special dynamic test loop at approximately 300°F. A static sample was irradiated simultaneously with the loop in each experiment. A preirradiation run at approximately the same temperature served to check out the loop mechanically and provide base-line data on each oil.

Five separate experiments were completed: the irradiation of each of the three oils under similar conditions in order to compare the oils; and two additional irradiations on MIL-L-7808C at relatively higher and lower exposure rates in order to study the effects of varying this parameter.

MIL-L-7808C was irradiated to a maximum exposure of 1.2×10^{10} ergs/gm(C) of gamma dose and 9.6×10^{14} n/cm^2 (E_n 2.9 Mev). GTO-790 was exposed to a maximum of 7.4×10^9 ergs/gm(C) and 5.8×10^{14} n/cm^2 (E_n 2.9 Mev) and MIL-L-9236B to 1.1×10^{10} ergs/gm(C) and 6.3×10^{14} n/cm^2 (E_n 2.9 Mev).

Oil samples were taken periodically during each irradiation. A comparison of the chemical and physical properties of these

irradiated samples with the properties of the new oil and samples from the pre-irradiation loop run indicated the extent of radiation damage.

Each oil operated satisfactorily in the loop prior to irradiation. All three oils, however, suffered extensive loss of important properties during irradiation under both dynamic and static conditions. Dynamic conditions accentuated this damage. With the increase in coking tendency and neutralization number as a criterion, tests showed MIL-L-7808C to be damaged more severely by its irradiation than the other two oils, which suffered about the same damage.

The radiation damage to MIL-L-7808 may have been partially dependent upon the exposure rate.

The techniques developed for these experiments can be adapted for the evaluation of more exotic lubricants as well for the inclusion if additional parameters required by unique systems design specifications.

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I. INTRODUCTION

Damage to materials resulting from exposure to nuclear radiation is being investigated at General Dynamics/Fort Worth (GD/FW). This work includes an effort to determine which materials are most suitable for use in combined nuclear and non-nuclear environments.

One phase of this effort has been concerned with the experimental screening of turbine lubricating oils. The objective of this phase is to ascertain the extent to which each oil retains its important properties under simultaneously imposed conditions of temperature, mechanical shear stress, and reactor irradiation. As a part of this work, three typical turbine oils were irradiated during the 1958 to 1961 period. These oils - a qualified MIL-L-7808C oil, a complex ester-type oil identified as GTO-790, and a qualified MIL-L-9236B oil - were selected because they represent lubricants for use in three temperature ranges.

The Ground Test Reactor (GTR) served as the mixed-field radiation source. A simple Dynamic Test Loop was used to maintain temperature and mechanical shear conditions during irradiation. A static vessel located inside the reservoir of the Dynamic Test Loop provided statically irradiated samples for comparison with those circulated in the loop. Remote-sampling techniques allowed test samples to be withdrawn during irradiation, providing data from a wide range of exposures.

Irradiated samples were subjected to a number of property and performance tests which experience has shown will detect radiation damage in lubricating oils. Damage was evaluated on the basis of comparisons between test data from the irradiated samples and similar data from non-irradiated control samples.

Altogether, five irradiations were completed. In three of these, one on each oil, the environmental conditions were duplicated as nearly as possible so that the resulting data could be compared. The two additional runs were on MIL-L-7808C and were accomplished at widely varying dose rates and total run times. Data from these two runs, together with the other MIL-L-7808C irradiation, yielded some insight into the variation of damage as a function of radiation dose rate.

Separate samples of the three oils were placed in special test cylinders designed so that the pressure buildup and the temperature above each oil could be continuously monitored during exposure. Ideal-gas formulas were used to convert these data to a quantitative expression of gas evolution per unit of radiation dose.

Summary data on all five irradiations have been previously reported in NARF Semi-Annual Progress Reports on Radiation Effects (Refs. 1 through 4).

II. MATERIALS AND EQUIPMENT

The Ground Test Reactor (GTR), used for all irradiations discussed in this report, is a water-cooled, water-moderated, thermal reactor utilizing MTR-type fuel elements. The GTR has an AEC-authorized 3-Mw capability, and is the primary source for radiation-effects testing at GD/FW.

The irradiation of materials and assemblies by the GTR is facilitated by a shuttle system, which transports the test items into and out of the high-flux region. This system can transport assemblies weighing up to 1 ton and having dimensions limited to an exposure face of approximately 3 x 3 feet and a length of 5 feet. The GD/FW radiation-effects test facilities are discussed in detail in Reference 5. Figure 1 presents a plan view of the overall transport and reactor system, showing also a test assembly similar in size to the Dynamic Test Loop (Sec. 2.2) used in the oil irradiations.

To determine the property changes induced by the radiation environment, unused samples of the three aircraft jet-turbine lubricating oils were tested in the GD/FW lubricants laboratory. The results of these tests are presented in Table I; the oils are further described in Section 2.1.

2.1 Three Jet-Turbine Oils

MIL-L-7808C. The sample selected was a typical, high-quality, sebacate-base fluid purchased commercially from the Sinclair Refining Company as Turbo S Oil (L-697). MIL-L-7808

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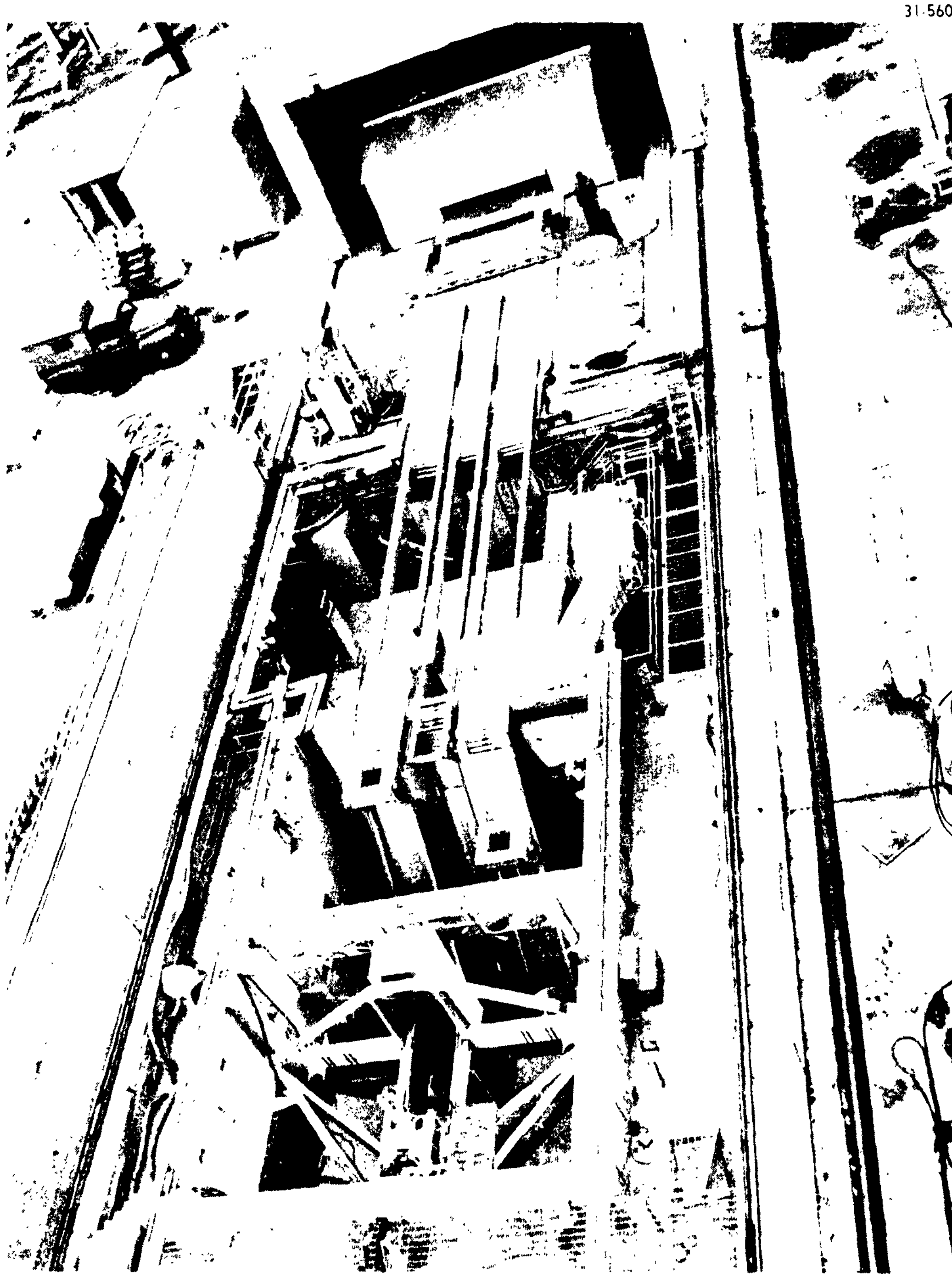

FIGURE 1. MATERIALS TRANSPORT AND REACTOR SYSTEM

TABLE I

PROPERTIES OF UNIRRADIATED AIRCRAFT TURBINE OILS

Property	MIL-L-7808C (Sinclair Turbo S-L-697	GTO-790	MIL-L-9236B (GTO-915)
Kinematic Viscosity (centistokes)			
@ -65°F	11,802.00	--	--
@ -40°F	--	9,980.00	--
@ 100°F	21.43	27.56	15.96
@ 210°F	5.50	5.18	3.57
@ 400°F	--	1.31	1.07
Neutralization Number (mg KOH/gm Oil)	0.08	0.09	0.02
Flash Point, COC (°F)	440	484	465
Fire Point, COC (°F)	505	--	510
Pour Point (°F)	-95	-75	-90
Evaporation Loss (% in 6-1/2 hr @ 400°F)	22.56	10.32	15.03
Coking Tendency			
Coke Formed @ 600°F (mg)	9.1	30.4	33.9
Coke Formed @ 700°F (mg)	--	--	127.35
Oil Consumed @ 600°F (ml)	187	95.0	168
Oil Consumed @ 700°F (ml)	--	--	428
Lubricity (Shell Four-Ball Wear)			
1 hr @ 130°F, 1800 rpm			
Average Scar Diameter (mm): 20 kg Load	0.289	0.96	0.686
Average Scar Diameter (mm): 40 kg Load	0.454	1.04	0.725
Coefficient of Friction: 20 kg Load	0.078	0.077	0.089
1 hr @ 400°F, 1800 rpm			
Average Scar Diameter (mm): 20 kg Load	--	--	0.818
Average Scar Diameter (mm): 40 kg Load	--	--	1.055
Coefficient of Friction: 20 kg Load	--	--	0.082
Oxygen-Induction Period: Time to absorb 0.5 mole/500 gm @ 400°F (hr)	24.1	57.7	71.0
Oxidation Corrosion			
Weight Change (mg/cm²)			
Copper	0.02	0.00	--
Steel	0.02	+0.10	--
Silver	0.01	+0.09	--
Aluminum	0.01	+0.08	--
Magnesium	0.03	+0.10	--
Appearance of Metal Specimens	Pass	Pass	--
% Viscosity Change (100°F)	+2.09	+12.55	--
Neutralization Number Change	+0.54	+0.377	--

defines a jet-turbine oil for use at temperatures of from $-65^{\circ}F$ to about $300^{\circ}F$. Oils of this type satisfy the turbine-lubricant requirements of most production-model high-performance jet engines currently in military use. Wide and satisfactory usage of the MIL-L-7808 type of oil has intensified interest in the oil as a candidate for future use in combined nuclear and non-nuclear environments. As a result of this interest, samples of MIL-L-7808 have been included in almost every radiation-effects program conducted on lubricating oils. Data on MIL-L-7808C listed in this report will supplement previously published data and provide a reference with which the data on the other two oils may be compared.

GTO-790. This designation refers to an experimental aircraft-turbine lubricant having a complex-ester base stock of relatively high molecular weight. The operating temperature range of GTO-790 is estimated to be from $-45^{\circ}F$ to $350^{\circ}F$. No military specification currently exists covering this specific temperature range, though it is encompassed by MIL-L-9236B. The GTO-790 was supplied by ASD for this test. Oil of this type is commercially available as Shell High Temperature Jet Oil A. Samples of GTO-790, coded as ANP-80, were exposed to gamma radiation at the Inland Testing Laboratories (Ref. 6). With thermal stability as the criterion, ANP-80 was concluded to be more resistant to gamma radiation than the MIL-L-7808 oils tested at Inland. The thermal stability was measured in a Model "C" Panel Coker and a WADD

Deposition Tester. No references have been found relating to the irradiation of GTO-790 type oil in a reactor flux.

MIL-L-9236B. A substituted-ester-base oil, coded as GTO-915, was also supplied by ASD for testing. MIL-L-9236B defines a jet-turbine oil for use at temperatures of from -65°F to 400°F. The exposure of GTO-915 to electrons and gamma rays under extreme temperature conditions (400°F to 700°F) is discussed in Ref. 7. No references have been found relating to the irradiation of MIL-L-9236 in a reactor flux.

2.2 Dynamic Test Loop

It has been well established that oils irradiated in static containers do not suffer the same property damage as oils irradiated in operating assemblies (Ref. 6). In an operating assembly, the oil is subjected to mechanical stresses and, perhaps, more mixing with air. Generally speaking, data obtained in operating assemblies are considered to be more representative of an oil's performance in final application.

A simple Dynamic Test Loop was fabricated at GD/FW for the oil irradiations covered by this report. The use of this loop provided a means of imposing thermal stress and mechanical shear on the lubricants during exposure to reactor radiation.

The Dynamic Test Loop consists of a pump, reservoir assembly, filter, restrictor valve, bypass valve, and various pressure and temperature sensors. The components are suitably

insulated and mounted with the necessary plumbing into an aluminum framework. Figure 2 is a block diagram of the Dynamic Test Loop. Figure 3 shows photographs of the front (reactor side) and rear of the assembled loop.

The Test Loop was designed to (a) maintain bulk-oil temperature at the desired level (80°F to 300°F), (b) pressurize the circulating oil to 60 psig, and (c) force the oil through a restrictor valve at approximately 2 gpm. A general description of the major loop components follows.

> <u>Pump</u> - a lubricating-oil pump normally used on J-47 turbojet engines. In the first two irradiations, a three-element, gear-type, constant-displacement pump was used, and in the last three a geroter-type pump. A 7.5-hp, 3750-rpm electric motor powered the pump.
>
> <u>Reservoir Assembly</u> - an 8-gal, rectangular, aluminum vessel containing two 750-watt immersion heaters; a circulating-water cooling coil; liquid-level transmitter; temperature probes; and a 1-gal, rectangular, "static fluid" reservoir.
>
> <u>Filter</u> - an aircraft-type filter, normally used on J-47 turbojet engines, with cleanable, disc-type, metal-screen filter elements. Filter pore diameters are approximately 60 microns.
>
> <u>Restrictor Valve</u> - a common globe valve manually adjustable to provide the desired pressure.
>
> <u>Bypass Valve</u> - an adjustable pressure-relief valve set to bypass oil directly to the reservoir at 75 psig.

Instrumentation was provided to measure pump pressure and the pressure differential across the filter. Oil temperature was measured at three points in the circulating system. Connections were provided for remote sampling of the oil in

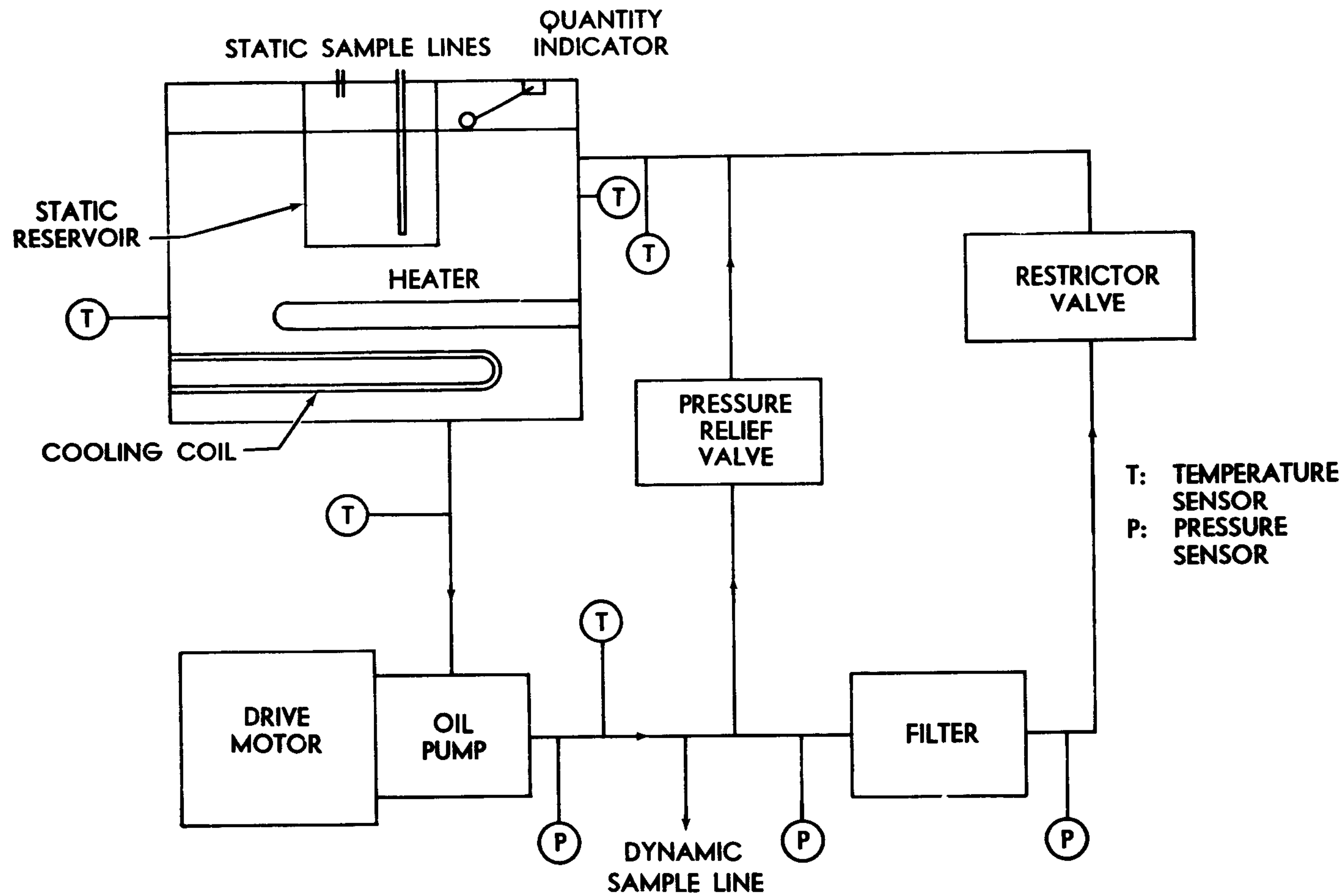

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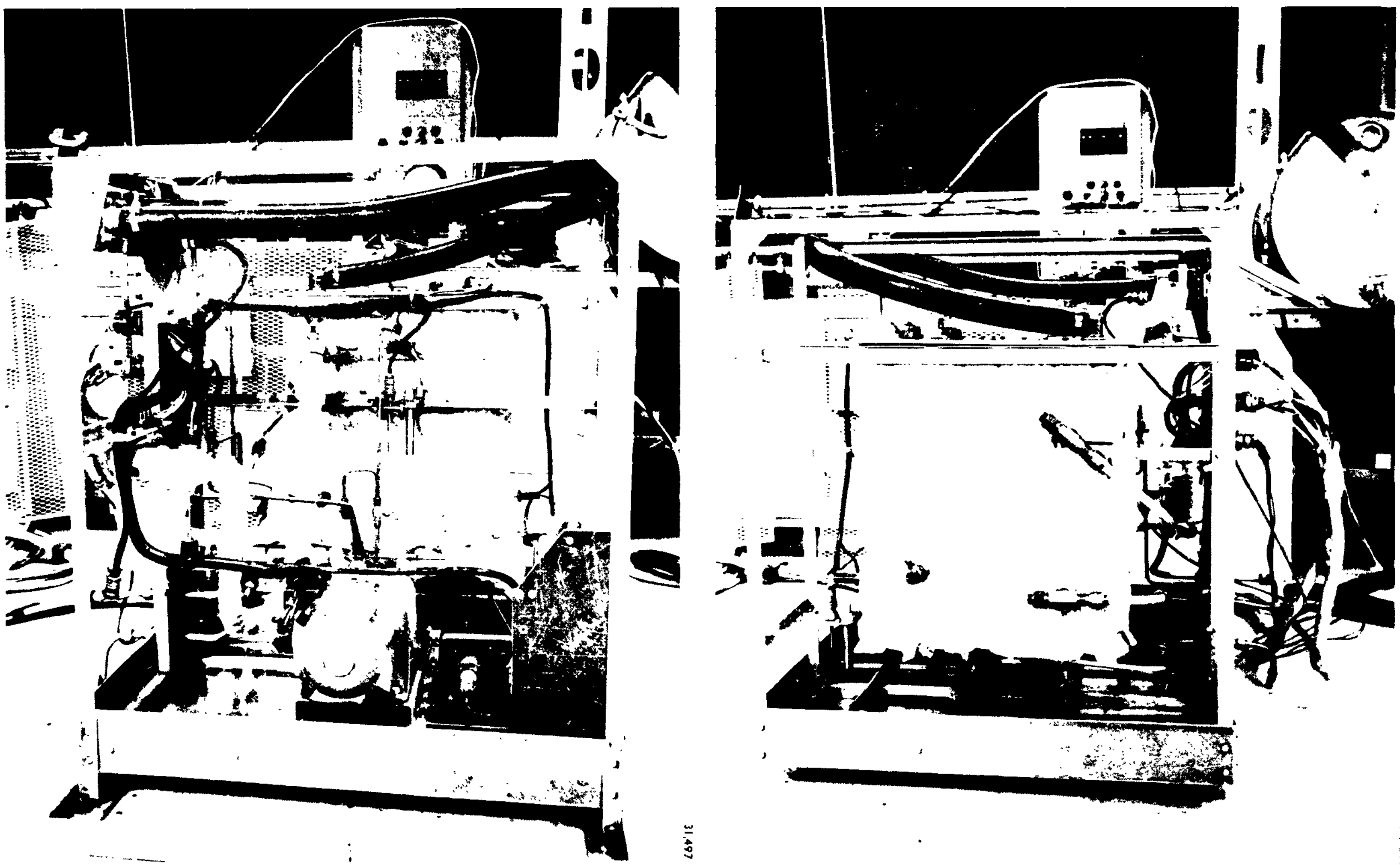
FIGURE 2. BLOCK DIAGRAM - DYNAMIC OIL-TEST LOOP



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31,4599

Front View

Rear View

FIGURE 3. DYNAMIC OIL-TEST LOOP

the static reservoir by air pressurization. Oil in the dynamic portion of the loop was sampled through a line connected to the pressure side of the oil pump. Sampling lines were 0.25-inch copper tubing approximately 110 feet long.

2.3 Special Equipment

Two pieces of test equipment used in testing the oils discussed in this report are unique to GD/FW. These are described below.

2.3.1 Oxygen-Absorption Apparatus

This apparatus, shown in Figure 4, consists of a laboratory setup containing a regulated air supply, a reaction vessel where the air is bubbled into a 200-cc oil sample, and an analyzer for measuring the oxygen content of the exit gas. The reaction vessel is immersed in an oil bath for temperature control. A copper catalyst is used to accelerate the reaction. The quantity calculated is in moles of oxygen absorbed per unit weight of oil. The test may be described as a "Modified Dornte Oxidation Test" (Ref. 8).

2.3.2 Gas-Evolution Cylinders

Figure 5 is a section view of one of the special aluminum cylinders designed for remote monitoring of the pressure and temperature developed above the fluids during irradiation. A calibrated pressure transmitter operating in the 0-400 psig range and a standard thermocouple probe are mounted in the threaded O-ring sealing lid of each

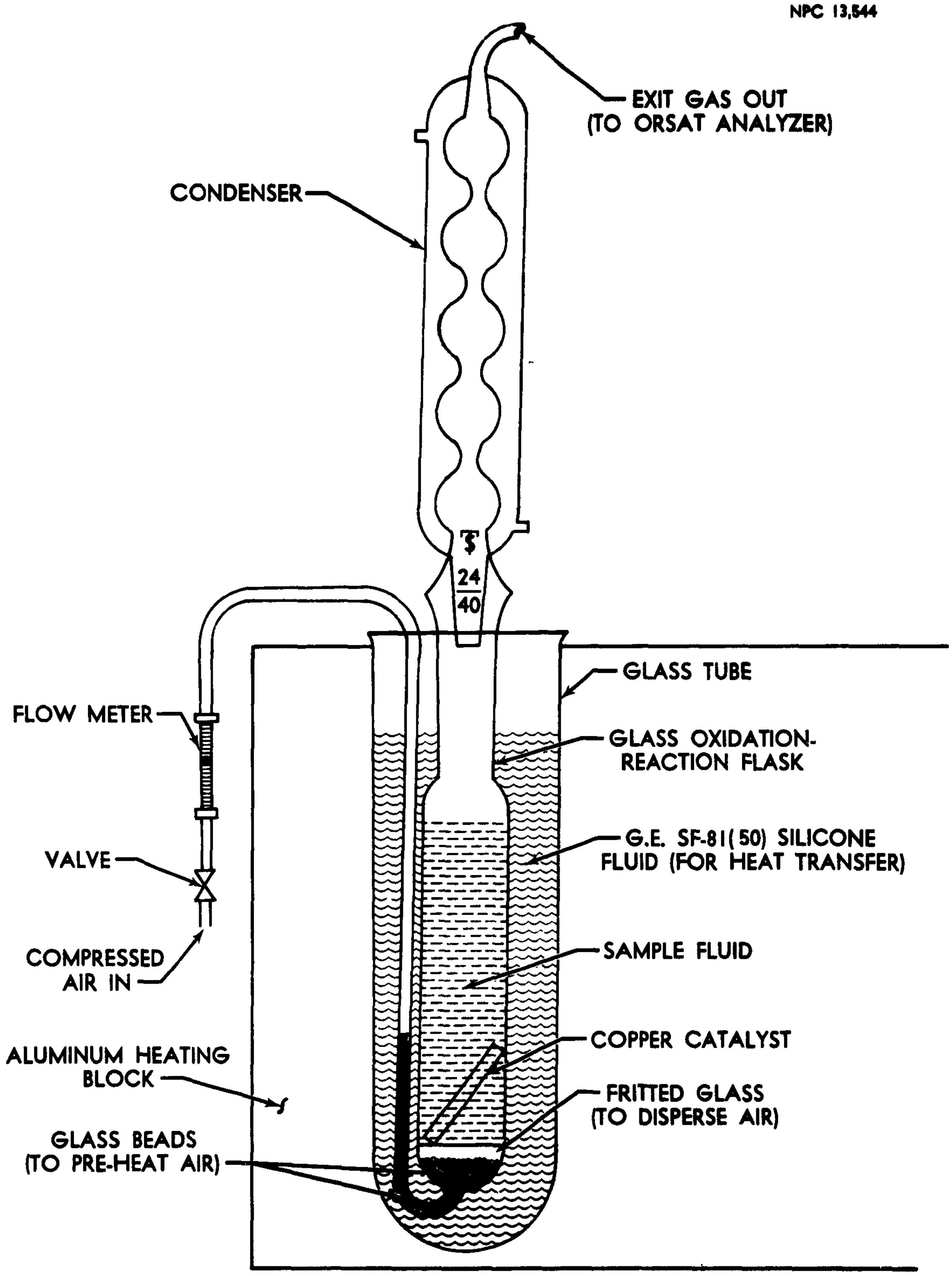

FIGURE 4. OXYGEN ABSORPTION RATE SETUP

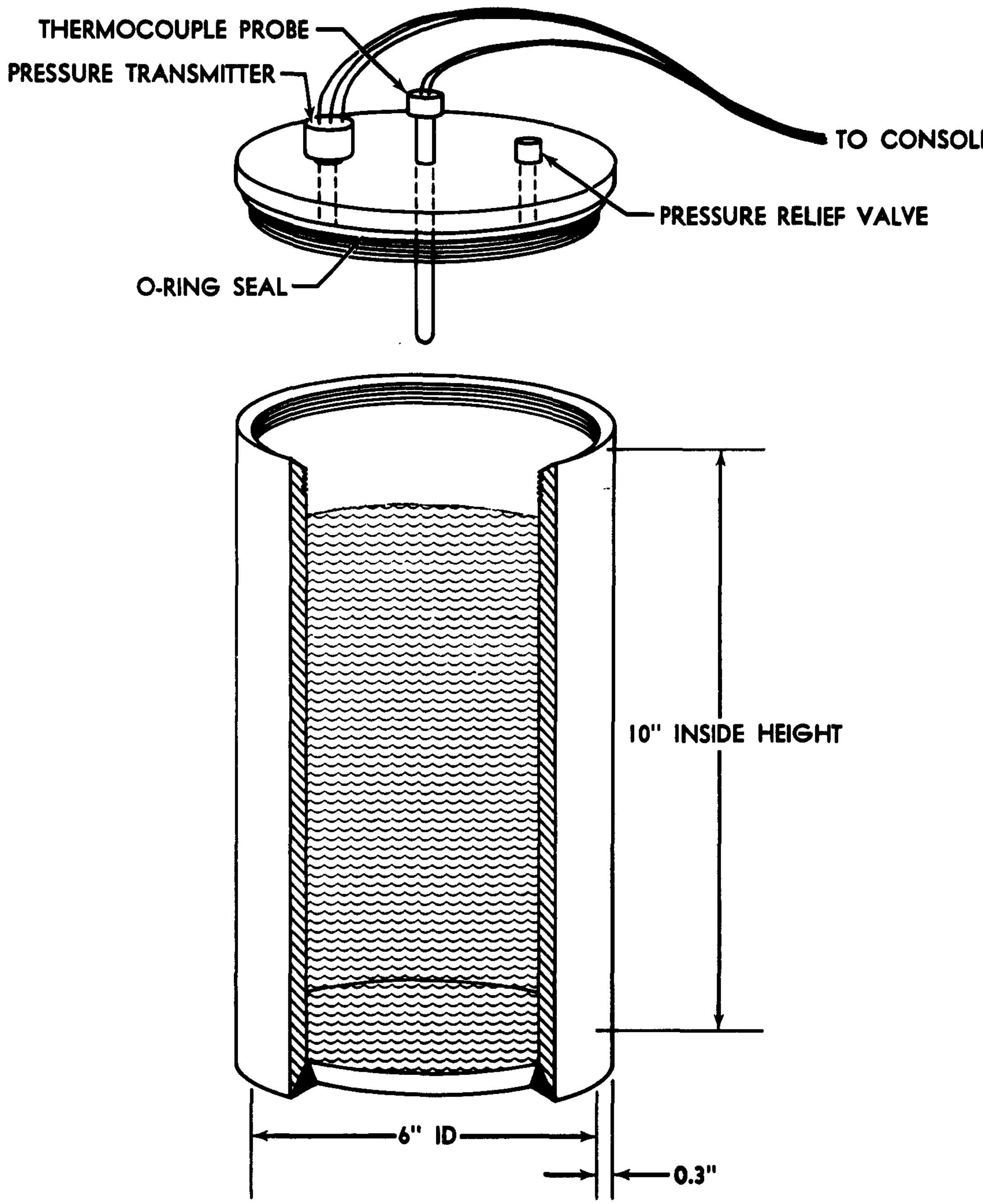

FIGURE 5. IRRADIATION CYLINDER FOR GAS-EVOLUTION MEASUREMENTS

cylinder. The cylinder volume is 4400 ml. Each fluid volume was adjusted so as to yield pressure buildup during irradiation in the linear response region of the pressure transmitters. About 3900 ml were required. Figure 6 shows six of these cylinders mounted in an aluminum framework suitable for irradiation.

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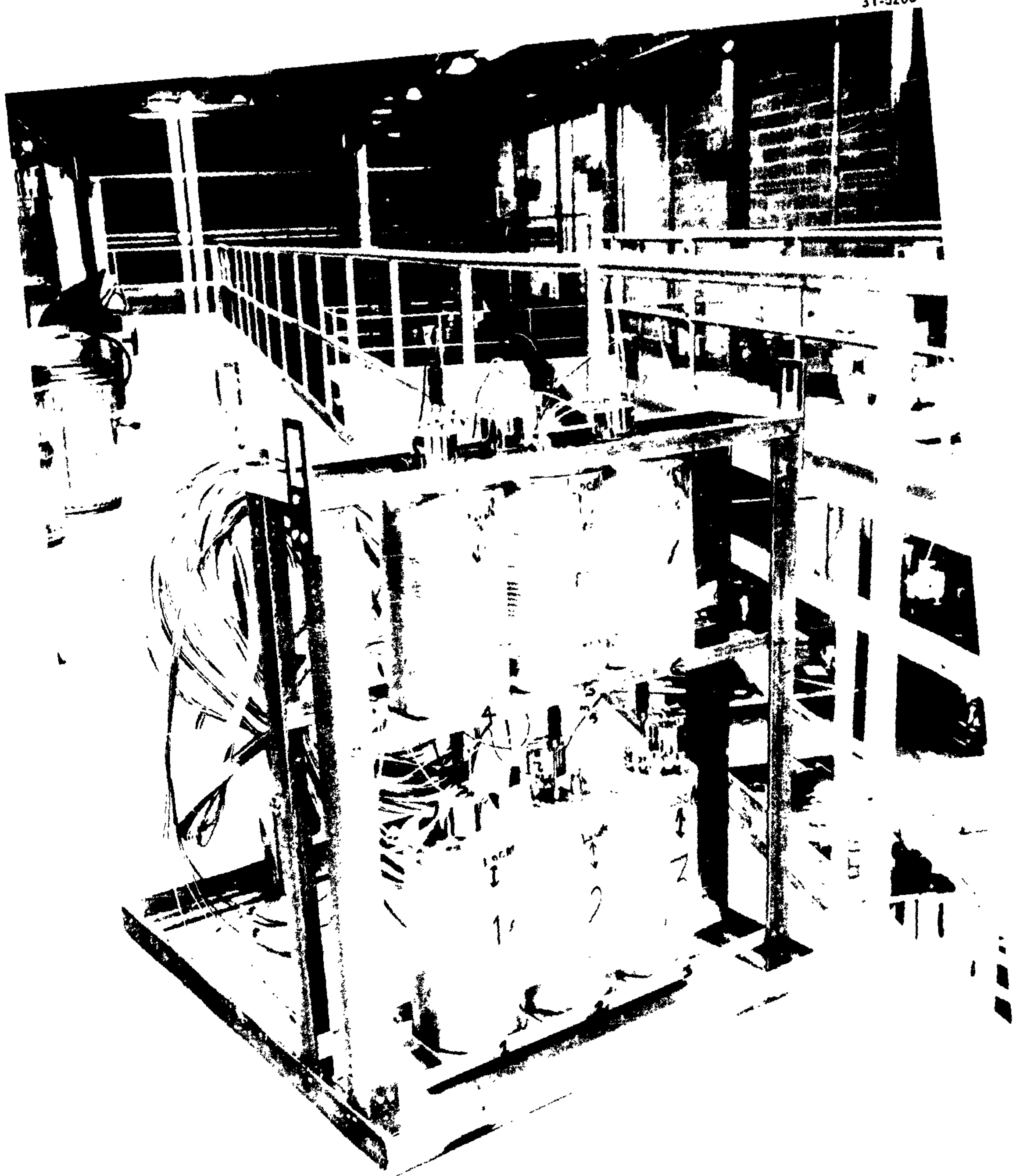

FIGURE 6. IRRADIATION CYLINDERS FOR GAS-EVOLUTION MEASUREMENTS - IRRADIATION SETUP

III. IRRADIATION PROCEDURES

3.1 Irradiation Sequence and Conditions

The important experimental conditions for each of the five irradiations are listed in Table II according to the chronological order of the experiment.

3.2 Radiation Dose and Flux Measurements

3.2.1 Gamma Dosimeters

The quantity of gamma radiation incident on the reservoir of the Dynamic Test Loop was measured during the first two MIL-L-7808C experiments with tetrachloroethylene chemical dosimeters (Ref. 9). Nitrous-oxide gamma dosimeters (Ref. 10) were used in the other three irradiations, because they were felt to be more reliable in the temperature and dose environments of those experiments. At the time of the first MIL-L-7808C experiment (Run 1) the nitrous-oxide dosimeters had not been fully developed; and, although they were available for the second experiment, the chemical dosimeters were considered more appropriate for the gamma dose involved.

In each Dynamic Loop experiment, measured gamma-dose values from five dosimeters were arithmetically averaged to obtain the total incident gamma dose. The dosimeters were located one each on the approximate center and corners of the reactor side of the Dynamic Loop reservoir. The incident gamma dose on each of the gas-evolution cylinders was measured by a single nitrous-oxide dosimeter. Readout data from both

TABLE II

OIL IRRADIATIONS-EXPERIMENTAL CONDITIONS

	1. MIL-L-7808C (Run 1)
Preirradiation	20-hour loop run at 275°F
Irradiation	4-hour dynamic run at 275°F 6-hour static run at 275°F
Gamma Dose Rate	2(9)* ergs/gm(C)-hr
Neutron Flux	3.3(10) n/cm^2-sec, E_n > 2.9 Mev
Maximum Gamma Dose	Dynamic - 8(9) ergs/gm(C) Static - 1.2(10) ergs/gm(C)
Maximum Integrated Neutron Flux	Dynamic - 4.8(14) n/cm^2 Static - 7.2(14) n/cm^2, E_n > 2.9 Mev
Postirradiation	No loop operation
Comments	Irradiated in September 1958. Test oil not changed after preirradiation run. Oil sampling as indicated in Table IV.
	2. MIL-L-2808C (Run 2)
Preirradiation	118-hour loop run at 300°F
Irradiation	50-hour loop run at 300°F 50-hour static run at 300°F
Gamma Dose Rate	4.6(6) ergs/gm(C)-hr
Neutron Flux	6.1(9) n/cm^2-sec, E_n > 2.9 Mev
Maximum Gamma Dose	2.3(8) ergs/gm(C)
Maximum Integrated Neutron Flux	1.1(13) n/cm^2, E_n > 2.9 Mev
Postirradiation	44-hour loop run at 300°F
Comments	Irradiated in December 1958. Test oil changed after preirradiation run but not between irradiation and postirradiation runs. Oil sampling as indicated in Table V.

* 2(9) denotes 2×10^9

TABLE II (Cont'd)

OIL IRRADIATIONS-EXPERIMENTAL CONDITIONS

	3. GTO-790
Preirradiation	50-hour loop run at 300°F
Irradiation	19.5-hour loop run at 300°F 19.5-hour static run at 300°F
Gamma Dose Rate	3.4(8) ergs/gm(C)-hr
Neutron Flux	8.3(9) n/cm^2-sec, $E_n > 2.9$ Mev
Maximum Gamma Dose	7.4(9) ergs/gm(C)
Maximum Integrated Neutron Flux	5.8(14) n/cm^2, $E_n > 2.9$ Mev
Postirradiation	No loop operation
Comments	Irradiated in September 1959. Test oil changed after preirradiation run. Oil sampling as indicated in Tables VIII and IX.
	4. MIL-L-9236B (GTO-915)
Preirradiation	20-hour loop run at 300°F
Irradiation	23-hour loop run at 300°F 23-hour static run at 300°F
Gamma Dose Rate	4.6(8) ergs/gm(C)-hr
Neutron Flux	7.6(9) n/cm^2-sec, $E_n > 2.9$ Mev
Maximum Gamma Dose	1.1(10) ergs/gm(C)
Maximum Integrated Neutron Flux	6.3(14) n/cm^2, $E_n > 2.9$ Mev
Postirradiation	No loop operation
Comments	Irradiated in March 1960. Test oil changed after preirradiation run. Oil sampling as indicated in Tables X and XI.

TABLE II (Cont'd)

OIL IRRADIATIONS-EXPERIMENTAL CONDITIONS

5. MIL-L-7808C (Run 3)	
Preirradiation	20-hour loop run at 300°F
Irradiation	20-hour loop run at 300°F 20-hour static run at 300°F
Gamma Dose Rate	4.3(8) ergs/gm(C)-hr
Neutron Flux	7.2(9) n/cm^2-sec, $E_n > 2.9$ Mev
Maximum Gamma Dose	8.6(9) ergs/gm(C)
Maximum Integrated Neutron Flux	5.1(14) n/cm^2, $E_n > 2.9$ Mev
Postirradiation	No loop operation
Comments	Irradiated in July 1960. Test oil changed after preirradiation run. Oil sampling as indicated in Tables V and VI.

the tetrachloroethylene and nitrous-oxide dosimetry systems are estimated to be accurate within 20% for all the conditions encountered in the oil experiments.

3.2.2 Neutron Detectors

The fast-neutron flux incident on the Dynamic Loop reservoir was measured with threshold detectors: sulfur tablets with a 2.9-Mev effective-energy threshold; magnesium discs with a 7.8-Mev threshold; and aluminum discs with an 8.1-Mev threshold. Neutron detectors were located with each gamma dosimeter on the loop reservoir and also on the special gas-evolution cylinders. The neutron spectrum prevalent in the GTR irradiation volume has been defined and reported in Reference 11. The neutron flux above 2.9 Mev is listed in the present report. These values can be used to estimate the flux above any energy level of interest by consulting the spectrum in Reference 11. The flux above 10 kev, for example, may be approximated by multiplying the flux values above 2.9 Mev by a factor of 5.8. A neutron energy of 10 kev is sometimes considered the minimal energy for damage to organic materials (Ref. 12).

3.2.3 Self-Shielding Considerations

A significant self-shielding effect has been shown to be present when large oil samples are irradiated (Ref. 13). This effect causes the average radiation dose on all portions of the oil to be considerably less than the dose reaching the

exterior of the sample. The average flux and dose values for oil in the Dynamic Test Loop (Tables IV through XII, Sec. IV) were obtained by correcting the incident dose as follows:

$$\phi_{average} = \frac{1}{T} \int_0^T \phi \text{ incident } e^{-\Sigma x} \, dx$$

T = thickness of oil samples (cm)

$\phi_{incident}$ = measured gamma dose or neutron flux

Σ = total-absorption coefficient for gamma radiation or neutrons based on an assumed oil formulation of di-2-ethylhexyl sebacate.

$$\Sigma_\gamma = 0.062 \text{ cm}^{-1} \ (E_{avg} = 1.25 \text{ Mev})$$
$$\Sigma_n = 0.218 \text{ cm}^{-1} \ (E = 2.9 \text{ Mev})$$

In order to use the above equation, several assumptions were necessary:

a. Scattering into the system was negligible.

b. The shielding properties of each oil were those of di-2-ethylhexyl sebacate with the density of MIL-L-7808. The absorption coefficients used would be similar for any hydrocarbon oil. Since the exact compositions of the test oils were unknown to the writer, this assumption appeared reasonable and necessary.

c. The "static" oil samples, which were centrally located inside the Dynamic Test Loop reservoir, received the same radiation as the average on the respective dynamic sample. This assumption should be accurate to within 10%.

The average flux and dose on the oil samples irradiated in the gas-evolution cylinders were corrected by use of the equation given above, with an additional correction in T for the cylindrical geometry. The value of T was estimated by

calculating an effective fluid thickness:

$$T^2 = \pi r^2$$

T = effective fluid thickness = the side of a square containing the area bounded by the inner circumference of the cylinder.

r = inside radius of cylinder

IV. TEST METHODS AND RESULTS

A number of property and performance tests were conducted on the irradiated oil samples and on fresh (control) samples. Table III lists these tests along with the methods followed in conducting each. With the exception of the modified Dornte oxidation tests and the gas-evolution measurements, testing was in accordance with published methods using standard equipment. The unique equipment used for these two tests is discussed in Section 2.3

4.1 MIL-L-7808C (Sinclair Turbo S-L-697)

4.1.1 Run 1

The test results from the first run on MIL-L-7808C are listed in Table IV. The irradiation rate of 2×10^9 ergs/gm(C)-hr gammas and 1.2×10^{14} n/cm^2-sec associated neutron flux was the highest imposed on any oil discussed in this report, and the exposure time was the shortest. The oil viscosity and flash point decreased sharply during irradiation, while neutralization number and copper corrosion properties increased sharply. Changes in each property were detrimental. Property losses were more severe in the dynamic samples than in those irradiated statically, but the oil is considered to have degraded to an unsatisfactory state under both conditions.

4.1.2 Run 2

The test data from the second experiment on MIL-L-7808C are listed in Table V. The irradiation rate of 4.6×10^6

TABLE III

METHODS OF TEST-AIRCRAFT TURBINE OILS

Test	Method
Kinematic Viscosity (centistokes)	
@ -65°F	ASTM D445-53T
@ -40°F	ASTM D445-53T
@ 100°F	ASTM D445-53T
@ 210°F	ASTM D445-53T
@ 400°F	ASTM D445-53T
Neutralization Number (mg KOH/gm oil)	ASTM D664-54
Flash Point, COC (°F)	ASTM D92-57
Fire Point, COC (°F)	ASTM D92-57
Pour Point (°F)	ASTM D97-57
Evaporation Loss (% in 6-1/2 hrs @ 400°F)	MIL-L-7808C, Par. 4.5.11
Coking Tendency	
@ 600°F	MIL-L-7808C, Par. 4.5.10
@ 700°F	MIL-L-9236A, Par. 4.5.9
Oxidation/Corrosion Stability	MIL-L-7808C, Par. 3.4.1
Lubricity	Shell Four-Ball Wear Test: 1 hr, 1800 rpm; 20 and 40 kg loads; 130°F and 400°F.
Oxygen-Induction Period: Time to absorb 0.5 mole oxygen/500 gm oil (hr)	GD/FW modified Dornte oxidation test: air flow rates of 5 ℓ/hr; Cu_2 catalyst (0.1935 cm^2/gm oil); 100 gm oil sample; 375°F to 500°F.
Gas Evolution (ml gas/ml fluid per unit radiation dose)	Pressure buildup in a sealed container measured during irradiation.

TABLE IV

EFFECTS OF IRRADIATION ON MIL-L-7808C, RUN 1 *
(AVERAGE TEMPERATURE 275°F)

Preirradiation Dynamic Operation (hr)	0	20	20	20	20	20	0	0	0	0	0	0
Dynamic Irradiation (hr)	0	0	0.5	1	2	4	0	0	0	0	0	0
Preirradiation Static Condition (hr)	0	0	0	0	0	0	20	20	20	20	20	20
Static Irradiation (hr)	0	0	0	0	0	0	0	0.5	1	2	4	6
Average Gamma Dose [ergs/gm(C)]	0	--	1(9)	2(9)	4(9)	8(9)	--	1(9)	2(9)	4(9)	8(9)	1.2(10)
Average Integrated Neutron Flux (n/cm^2, $E_n > 2.9$ Mev)	0	--	6(13)	1.2(14)	2.4(14)	4.8(14)	--	6.0(13)	1.2(14)	2.4(14)	4.8(14)	9.6(14)
Viscosity (centistokes)												
@ -65°F	13,050	13,231	--	--	--	12,875	12,844	--	--	--	--	13,340
@ 100°F	22.43	22.06	21.78	18.34	16.41	15.99	22.46	20.34	19.84	18.71	17.47	16.54
@ 210°F	5.69	5.60	5.47	4.51	4.01	3.87	5.69	5.06	4.95	4.61	4.24	4.03
Neutralization Number	0.08	0.13	0.20	1.53	3.32	4.73	0.14	0.54	0.68	1.25	2.45	4.42
Flash Point (°F)	445	--	--	--	--	350	--	--	--	--	--	355
Precipitation Number	Nil	Nil	Trace	0.05	0.05	0.05	Nil	0.05	0.05	0.05	0.05	0.05
Pour Point (°F)	<-100	<-100	--	--	--	<-100	<-100	--	--	--	--	<-100
Evaporation Loss (% @ 400°F)	12.26	14.96	--	--	--	18.23	25.23	--	--	-	--	9.91
Oxidation/Corrosion												
Weight Change (mg/cm^2)												
Copper	+0.02	+0.02	--	--	--	--	+0.07	--	--	--	--	-18.94
Aluminum	+0.03	+0.03	--	--	--	--	+0.10	--	--	--	--	-0.17
Steel	+0.09	+0.07	--	--	--	--	+0.05	--	--	--	--	-0.40
Magnesium	-0.27	-0.09	--	--	--	--	-0.03	--	--	--	--	-0.15
Silver	+0.03	+0.04	--	--	--	--	+0.10	--	--	--	--	-0.06
Appearance Metal Specimens	Pass	Pass	--	--	--	--	Pass	--	--	--	--	Cu, Steel Fail
Neutralization Number Change	+1.15	+1.81	--	--	--	--	+1.79	--	--	--	--	+3.54
% Viscosity Change (100°F)	+3.97	+0.09	--	--	--	--	+0.85	--	--	--	--	+120.92

* See Table II for experimental conditions.

TABLE V

EFFECTS OF IRRADIATION ON
(AVERAGE TEMPERATU

Preirradiation Dynamic Operation (hr)	0	118	0	0	0	0	0	0
Dynamic Irradiation (hr)	0	0	0	7	12.50	18.50	25	31
Postirradiation Dynamic Operation (hr)	0	0	0	0	0	0	0	0
Preirradiation Static Conditions (hr)	0	0	118	0	0	0	0	0
Static Irradiation (hr)	0	0	0	0	0	0	0	0
Postirradiation Static Conditions (hr)	0	0	0	0	0	0	0	0
Average Gamma Dose [ergs/gm(C)]	0	0	0	3.2(7)	5.6(7)	8.3(7)	1.1(8)	1.4(8)
Average Integrated Neutron Flux (n/gm^2, $E_n > 2.9$ Mev)	0	0	0	1.5(12)	2.7(12)	4.0(12)	5.4(12)	6.7(12
Viscosity (centistokes)								
@ -65°F	12,318	12,373	12,881	--	--	--	--	--
@ 100°F	21.97	20.90	23.74	21.50	20.11	19.75	19.94	18.70
@ 210°F	5.63	5.30	5.59	5.46	5.07	5.03	4.90	4.74
Neutralization Number	0.11	3.41	1.47	0.33	1.55	1.75	2.46	3.32
Flash Point (°F)	445	445	445	445	465	440	425	450
Precipitation Number	Nil	0.50	Trace	Nil	Nil	Nil	Trace	0.08
Pour Point (°F)	<-100	<-100	<-100	--	--	--	--	--
Evaporation Loss (% @ 400°F)	17.5	29.7	27.1	--	--	--	--	--
Oxidation Corrosion								
Weight Change (mg/cm^2)								
Copper	-0.02	+0.74	+3.72	--	--	--	--	--
Aluminum	+0.01	+0.03	+0.03	--	--	--	--	--
Steel	-0.02	+0.03	+0.03	--	--	--	--	--
Magnesium	-0.03	+0.03	-0.02	--	--	--	--	--
Silver	-0.01	-5.07	+0.04	--	--	--	--	--
Appearance Metal Specimens	Pass	Cu, Mg Fail	Cu Fail	--	--	--	--	--
Neutralization Number Change	+0.54	-0.18	+0.71	--	--	--	--	--
% Viscosity Change (100°F)	+2.09	+2.30	-9.44	--	--	--	--	--

* See Table II for experimental conditions.

TABLE V

S OF IRRADIATION ON MIL-L-7808C, RUN 2 *
(AVERAGE TEMPERATURE 300°F)

0	0	0	0	0	0	0	0	0	0	0	0
25	31	37	43	50	50	50	50	50	0	0	0
0	0	0	0	0	10	22	34	44	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	50	50	50
0	0	0	0	0	0	0	0	0	0	22	44
1.1(8)	1.4(8)	1.7(8)	1.9(8)	2.3(8)	2.3(8)	2.3(8)	2.3(8)	2.3(8)	2.3(8)	2.3(8)	2.3(8)
5.4(12)	6.7(12)	8(12)	9.3(12)	1.1(13)	1.1(13)	1.1(13)	1.1(13)	1.1(13)	1.1(13)	1.1(13)	1.1(13)
--	--	--	--	12,595	--	--	--	13,029	11,008	--	11,968
19.94	18.70	18.45	18.43	18.35	18.22	18.10	18.05	18.25	17.74	16.59	16.69
4.90	4.74	4.67	4.64	4.65	4.53	4.57	4.54	4.53	4.60	4.20	4.22
2.46	3.32	3.74	4.01	4.25	5.05	5.43	6.12	6.41	1.22	2.33	2.78
425	450	435	400	400	435	415	420	335	450	420	415
Trace	0.08	0.02	0.10	0.20	0.30	0.30	0.34	0.40	Nil	Nil	0.05
--	--	--	--	<-100	--	--	--	<-100	--	--	<-100
--	--	--	--	30.1	--	--	--	21.5	32.7	--	24.4
--	--	--	--	--	--	--	--	+24.33	--	--	+8.63
--	--	--	--	--	--	--	--	+0.01	--	--	+0.03
--	--	--	--	--	--	--	--	+0.08	--	--	+0.03
--	--	--	--	--	--	--	--	-8.25	--	--	-0.25
--	--	--	--	--	--	--	--	+0.06	--	--	-0.01
--	--	--	--	--	--	--	--	Cu, Mg Fail	--	--	Cu, Mg Fail
--	--	--	--	--	--	--	--	-0.12	--	--	+2.15
--	--	--	--	--	--	--	--	+21.15	--	--	+17.44

ergs/gm(C)-hr gammas and 6.1×10^9 n/cm^2-sec associated neutron flux was the lowest of the five experiments, and the exposure time was the longest. Although changes were similar to those of Run 1, the rate of change was seen to vary considerably from Run 1 when plotted as a function of total radiation dose or of exposure time. A comparison of the test data from Runs 1 and 2 indicate that given property changes occurred at lower total dosage in Run 2.

In Run 2, operation of the Dynamic Test Loop was continued for 44 hours after removal from the radiation field. Viscosity continued to change, and neutralization number continued to rise at a rate which indicated that the MIL-L-7808C had lost its resistance to thermal and oxidative effects during the irradiation. The oil properties were degraded far beyond allowable limits.

The statically irradiated oil was sampled only at the end of the 50-hour irradiation because of a malfunction in the sampling system. Test data on this one sample indicate a loss of viscosity similar to the dynamic sample, but a much smaller rise in neutralization number. These properties continued to change in the static sample after irradiation, indicating that the static oil had also lost its resistance to thermal and oxidative effects.

It should be emphasized that a maximum exposure of only 2.3×10^8 ergs/gm(C) gamma dose and 1.1×10^{13} n/cm^2 integrated neutron flux was received by the test oil in Run 2.

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It should be emphasized that a maximum exposure of only 2.3 x 10^8 ergs/gm(C) gamma dose and 1.1 x 10^{13} n/cm^2 integrated neutron flux was received by the test oil in Run 2.

This quantity of radiation imposed under the conditions of the experiment degraded MIL-L-7808C to an unsatisfactory state.

4.1.3 <u>Run 3</u>

The test results from Run 3 are listed in Tables VI and VII. The third run on MIL-L-7808C was chronologically the fifth and last experiment covered in this report. Conditions for Run 3 were established to duplicate the test conditions imposed in the GTO-790 and MIL-L-9236B irradiations. Variations in damage to the dynamic and static samples were slight, but obvious, for Run 3. Figure 7 shows this variation for viscosity and neutralization number.

When considered as a function of total accrued dose, radiation damage to the Run 3 samples was more severe than that to the Run 1 samples, but less severe than damage to Run 2 samples. Figure 8 shows this relationship for changes in viscosity, neutralization number, and flash point. This damage relationship is in accord with other work which has established that dose rate, temperature, and oxidation or shearing forces are contributing factors to oil damage during irradiation (Refs. 5 and 14). When a lower dose rate is imposed, a longer time is required to accrue a given total dose. Consequently, damage agents such as thermal and shearing stresses are active for a longer time, and increased damage per unit of accrued dose results. This effect is treated in detail for oxygen-absorption rate in Reference 14.

TABLE VI

EFFECTS OF DYNAMIC IRRADIATION ON MIL-L-7808C, RUN 3 *
(AVERAGE TEMPERATURE 300°F)

Dynamic Irradiation (hr)	0	1	2	4	6	8	10	12	14	16	18	20
Average Gamma Dose [ergs/gm(C)]	0	4.3(8)	8.6(8)	1.7(9)	2.6(9)	3.4(9)	4.3(9)	5.2(9)	6.0(9)	7.3(9)	7.7(9)	8.6(9)
Average Integrated Neutron Flux (n/cm^2, $E_n > 2.9$ Mev)	0	2.6(13)	5.1(13)	1.0(14)	1.5(14)	2.0(14)	2.6(14)	3.1(14)	3.6(14)	4.1(14)	4.6(14)	5.1(14)
Viscosity (centistokes)												
@ -65°F	11,802	--	--	--	--	--	12,593	--	--	---	--	14,425
@ 100°F	21.43	16.62	15.36	14.57	14.55	14.55	14.67	14.95	14.92	15.12	15.35	15.72
@ 210°F	5.5	4.2	3.96	3.68	3.71	3.63	3.7	3.69	3.76	3.70	3.82	3.82
Neutralization Number	0.08	0.97	2.08	3.69	4.82	7.09	7.25	8.59	9.49	10.68	11.52	12.43
Flash Point (°F)	440	445	405	365	370	375	350	360	360	340	325	335
Fire Point (°F)	505	--	--	--	--	--	--	--	--	--	--	385
Pour Point (°F)	-95	--	--	--	--	--	-90	--	--	--	--	-90
Evaporation Loss (% @ 400°F)	22.56	--	--	--	--	--	27.13	--	--	--	--	28.58
Coking Tendency												
Coke Formed @ 600°F (mg)	9.1	--	--	--	--	--	545.2	--	--	--	--	1,634.7
Oil Consumed @ 600°F(ml)	187	--	--	--	--	--	200	--	--	--	--	200
Lubricity (Shell Four-Ball Wear)												
1 hr @ 130°F, 1800 rpm												
Average Scar Diameter (mm): 20 kg Load	0.289	--	--	--	--	--	0.350	--	--	--	--	0.323
Average Scar Diameter (mm): 40 kg Load	0.454	--	--	--	--	--	0.454	--	--	--	--	0.566
Coefficient of Friction: 20 kg Load	0.078	--	--	--	--	--	0.056	--	--	--	--	0.062
Oxygen-Induction Period: Time to absorb 0.5 mole/500 gm @ 400°F (hr)	24.1	--	15.1	--	--	--	18.3	--	--	--	--	16.

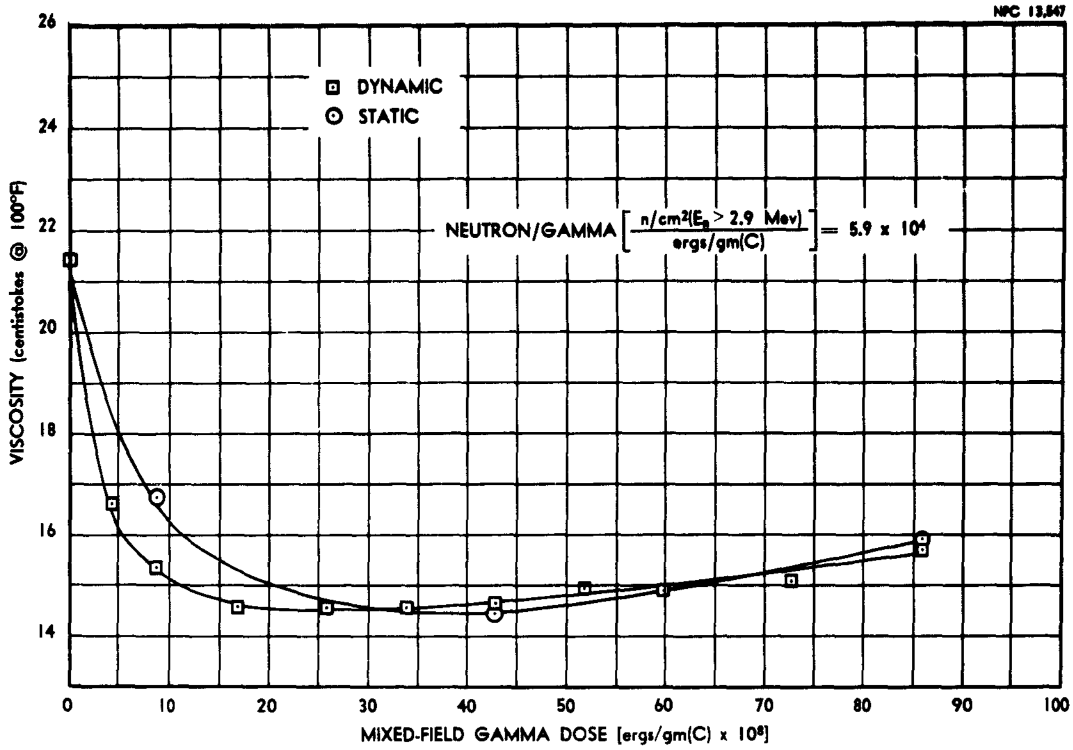
* See Table II for experimental conditions.

TABLE VII

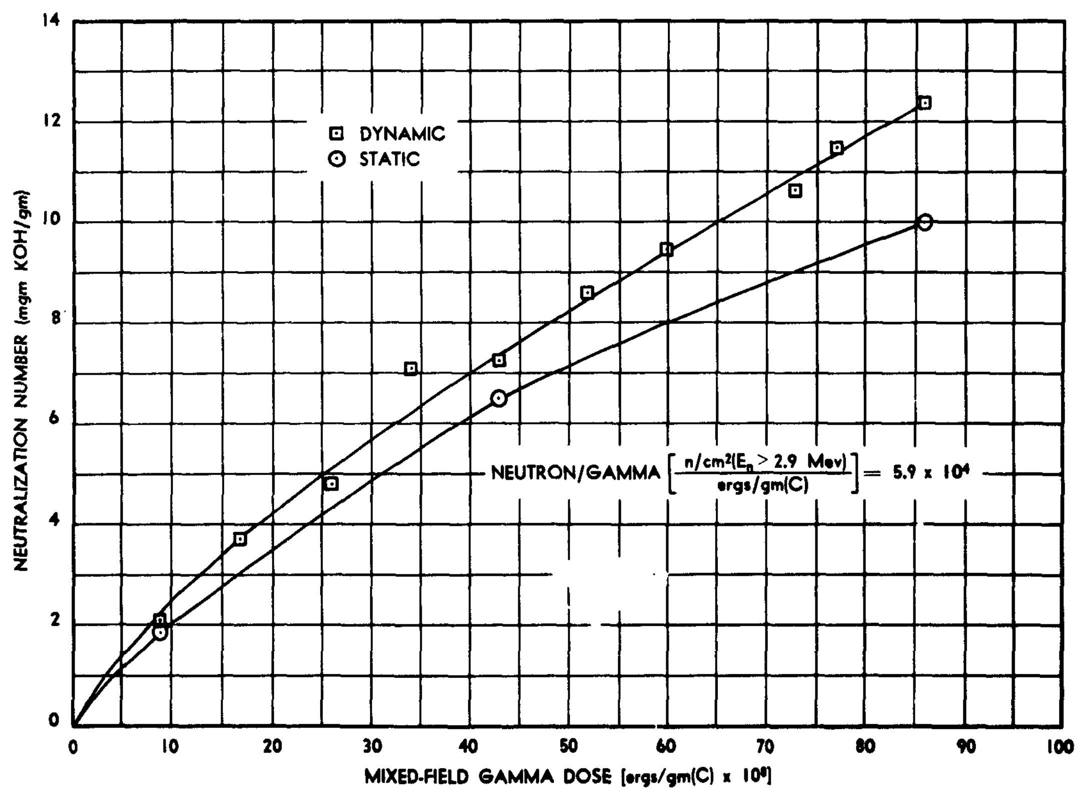
STATIC IRRADIATED AND DYNAMIC AND STATIC UNIRRADIATED *
DATA ON MIL-L-7808C, RUN 3
(AVERAGE TEMPERATURE 300°F)

Preirradiation Dynamic Operation (hr)	5	10	15	20	0	0	0	0
Preirradiation Static Conditions (hr)	0	0	0	0	20	0	0	0
Static Irradiation (hr)	0	0	0	0	0	2	10	20
Average Gamma Dose [ergs/gm(C)]	0	0	0	0	0	8.6(8)	4.3(9)	8.6(9)
Average Integrated Neutron Flux (n/cm^2, $E_n > 2.9$ Mev)	0	0	0	0	0	5.1(13)	2.6(14)	5.(14)
Viscosity (centistokes)								
@ -65°F	--	--	--	11,825	11,881	--	12,243	13,232
@ 100°F	20.54	20.58	20.44	20.38	21.04	16.72	14.49	15.19
@ 210°F	5.35	5.35	5.28	5.26	5.45	4.23	3.71	3.73
Neutralization Number	0.16	0.24	0.32	0.33	0.53	1.83	6.51	9.99
Flash Point, COC (°F)	--	--	--	420	450	455	340	320
Fire Point, COC (°F)	--	--	--	505	500	--	--	--
Pour Point (°F)	--	--	--	-95	-95	--	-90	-95
Evaporation Loss (% @ 400°F)	--	--	--	23.28	23.28	--	26.86	26.96
Coking Tendency								
Coke Formed @ 600°F (mg)	--	--	--	19.50	13.55	--	5.30	--
Oil Consumed @ 600°F (ml)	--	--	--	185	190	--	215.00	--
Lubricity (Shell Four-Ball Wear)								
1 hr @ 130°F, 1800 rpm								
Average Scar Diameter (mm): 50 kg Load	--	--	--	0.328	0.268	--	0.365	0.396
Average Scar Diameter (mm): 40 kg Load	--	--	--	0.435	0.499	--	0.464	0.412
Coefficient of Friction: 20 kg Load	--	--	--	0.059	0.061	--	0.064	0.062
Oxygen-Induction Period: Time to absorb 0.5 mole/500 gm @ 400°F (hr)	--	--	--	--	--	22.5	20.2	24.1

* See Table II for experimental conditions.

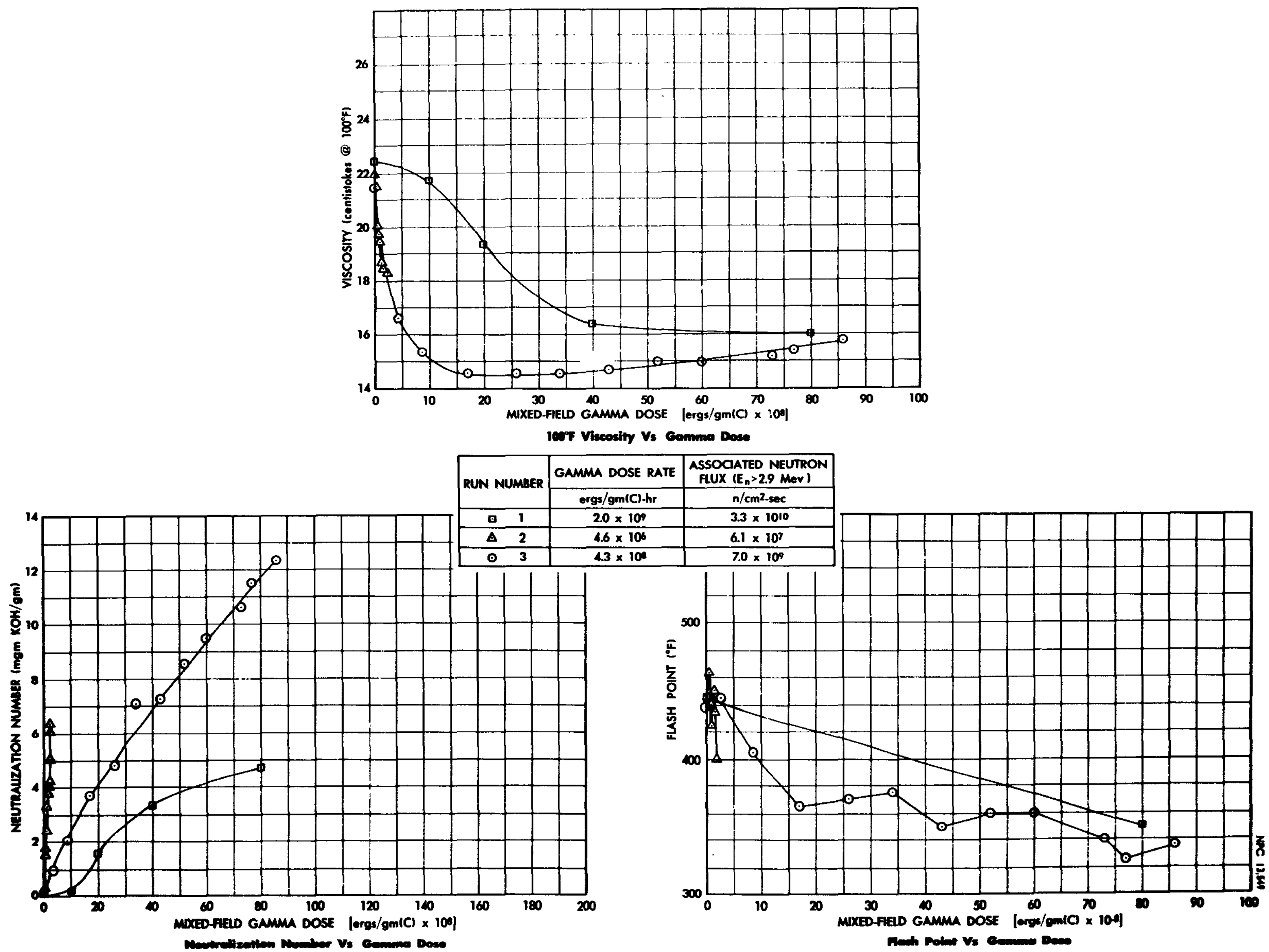


100°F Viscosity Vs Gamma Dose



Neutralization Number Vs Gamma Dose

FIGURE 7. DYNAMIC AND STATIC IRRADIATION OF MIL-L-7808 OIL: RUN 3



RUN NUMBER	GAMMA DOSE RATE	ASSOCIATED NEUTRON FLUX (E_n>2.9 Mev)
	ergs/gm(C)-hr	n/cm²-sec
□ 1	2.0×10^9	3.3×10^{10}
△ 2	4.6×10^6	6.1×10^7
⊙ 3	4.3×10^8	7.0×10^9

FIGURE 8. DYNAMIC IRRADIATION OF MIL-L-7808 OIL AT THREE DOSE RATES

Some property measurements not made on the Run 1 or Run 2 samples were begun on GTO-790 and continued for the MIL-L-9236B and Run 3 on MIL-L-7808C. These measurements were coking tendency, lubricity, and oxygen-absorption rate. Equipment for conducting the three additional tests was procured after the first two MIL-L-7808C irradiations.

Severe damage to the Run 3 samples was indicated by extremely large increases in coking tendency (Fig. 9) and neutralization number (Fig. 7). The viscosity decrease also appears excessive; however, the MIL-L-7808 specified minimum was not reached. The 130°F Shell Four-Ball Wear lubricity properties changed very little during the irradiation. A very large decrease in flash point occurred.

4.2 GTO-790

The test data from the dynamic irradiation of GTO-790 are listed in Table VIII. The static-irradiation data and the data from the unirradiated control run are listed in Table IX. Differences between property changes due to static and dynamic irradiations were slight, as indicated by Figure 10. Viscosity, neutralization number, metal corrosion, oxygen absorption, and coking tendency properties each increased; and flash point decreased. With the possible exception of the viscosity increase, these changes were detrimental to the oil. The maximum amount of coke formed at 600°F is considered moderate and only slightly above

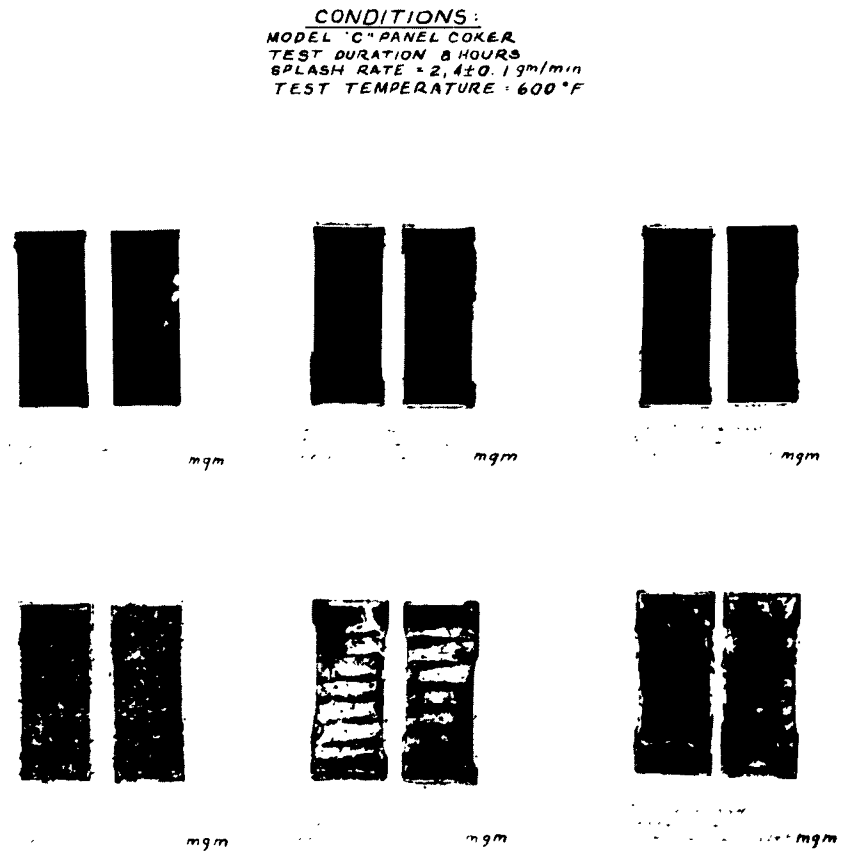


FIGURE 9. MIL L-7808 RUN-3 COKING PANELS

TABLE VIII

EFFECTS OF DYNAMIC IRRADIATION ON GTO-790 *
AVERAGE TEMPERATURE 300°F)

Dynamic Irradiation (hr)	0	1	2	4	6	8	10	12	14	16	18	19.5
Average Gamma Dose [ergs/gm(C)]	--	3.4(8)	6.8(8)	1.4(9)	2.3(9)	3.0(9)	3.8(9)	4.6(9)	5.3(9)	6.1(9)	6.8(9)	7.4(9)
Average Integrated Neutron Flux (n/cm^2, $E_n > 2.9$ Mev)	--	3.0(13)	6.0(13)	1.2(14)	1.8(14)	2.4(14)	3.0(14)	3.6(14)	4.2(14)	4.8(14)	5.4(14)	5.8(14)
Viscosity (centistokes)												
@ -40°F	9,980	--	--	--	--	--	13,584	--	--	--	--	17,960
@ 100°F	27.56	25.59	28.86	29.15	28.12	31.12	32.03	31.20	34.21	34.82	35.63	36.41
@ 210°F	5.18	5.17	5.30	5.41	5.38	5.64	5.82	5.64	5.96	6.00	6.10	6.28
@ 400°F	1.31	--	--	--	--	--	1.39	--	--	--	--	1.80
Neutralization Number	< 0.09	0.16	0.40	0.69	1.17	1.96	2.52	3.08	3.38	3.92	4.36	5.07
Flash Point (°F)	484	475	450	--	460	--	460	--	--	400	330	355
Pour Point (°F)	-75	--	--	--	--	--	-70	---	--	--	--	-65
Evaporation Loss (% in 6-1/2 hr @ 400°F)	10.32	--	--	--	--	--	10.49	--	--	--	--	11.85
Coking Tendency												
Coke Formed @ 600°F (mg)	30.4	--	--	--	--	--	4.2	--	--	--	--	118.6
Oil Consumed @ 600°F (ml)	95.0	--	--	--	--	--	95.0	--	--	--	--	100
Lubricity (Shell Four-Ball Wear)												
1 hr @ 130°F, 1800 rpm												
Average Scar Diameter (mm): 20 kg Load	0.96	--	--	--	--	--	0.70	--	--	--	--	0.72
Average Scar Diameter (mm): 40 kg Load	1.04	--	--	--	--	--	1.01	--	--	--	--	1.00
Coefficient of Friction: 20 kg Load	0.077	-	--	--	--	--	0.060	-	--	--	--	0.062
Oxidation/Corrosion												
Weight Change (mg/cm^2)												
Copper	0	--	--	--	--	--	-4.10	--	--	--	--	-7.33
Steel	+0.10	--	--	--	--	--	+0.07	--	--	--	--	+0.04
Silver	+0.09	--	--	--	--	--	+0.01	--	--	--	--	+0.02
Aluminum	+0.08	--	--	--	--	--	+0.03	--	--	--	--	+0.05
Magnesium	+0.10	--	--	--	--	--	-5.04	--	--	--	--	-10.52
Appearance of Metal Specimens	Pass	--	--	--	--	--	Mg, Cu Fail		--	--	--	Mg, Cu Fail
% Viscosity Change (100°F)	+12.55	--	--	--	--	--	+27.62	--	--	--	--	+38.84
Neutralization Number Change	+0.377	--	--	--	--	--	-0.67	--	--	--	--	-1.58
Oxygen-Induction Time: Time to absorb 0.5 mole/500 gm @ 400°F (hr)	57.5	--	--	--	--	--	7.60	--	--	--	--	3.9

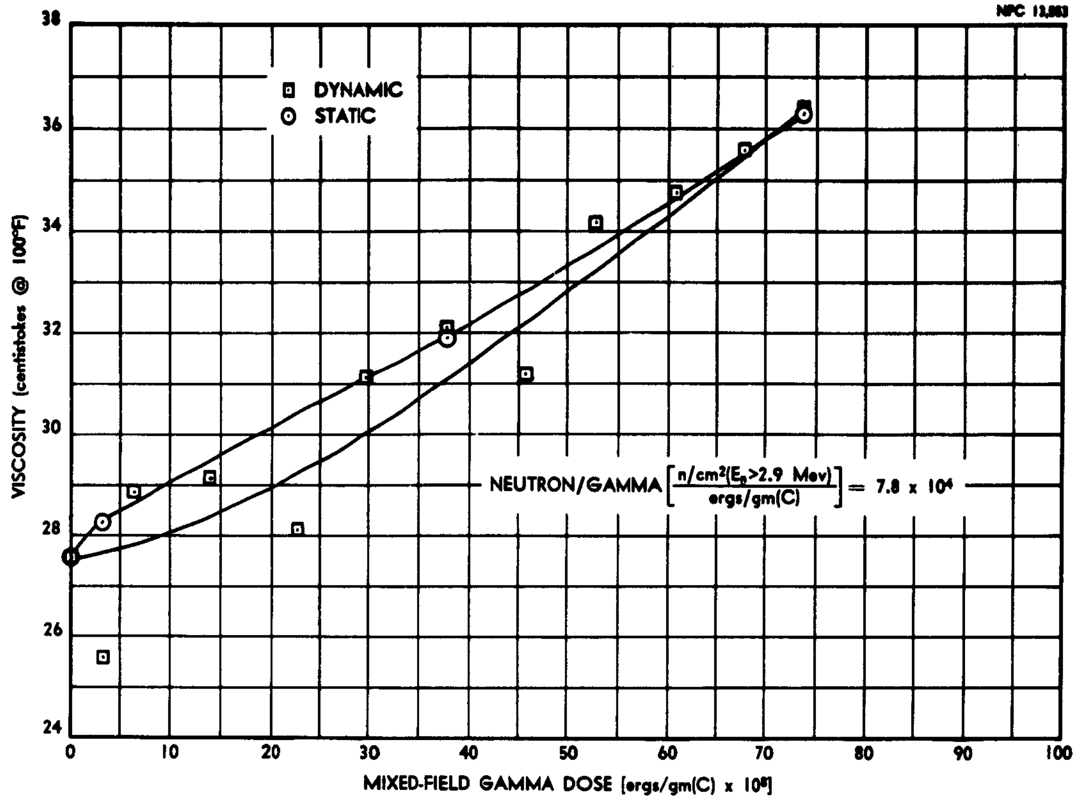
* See Table II for experimental conditions.

TABLE IX

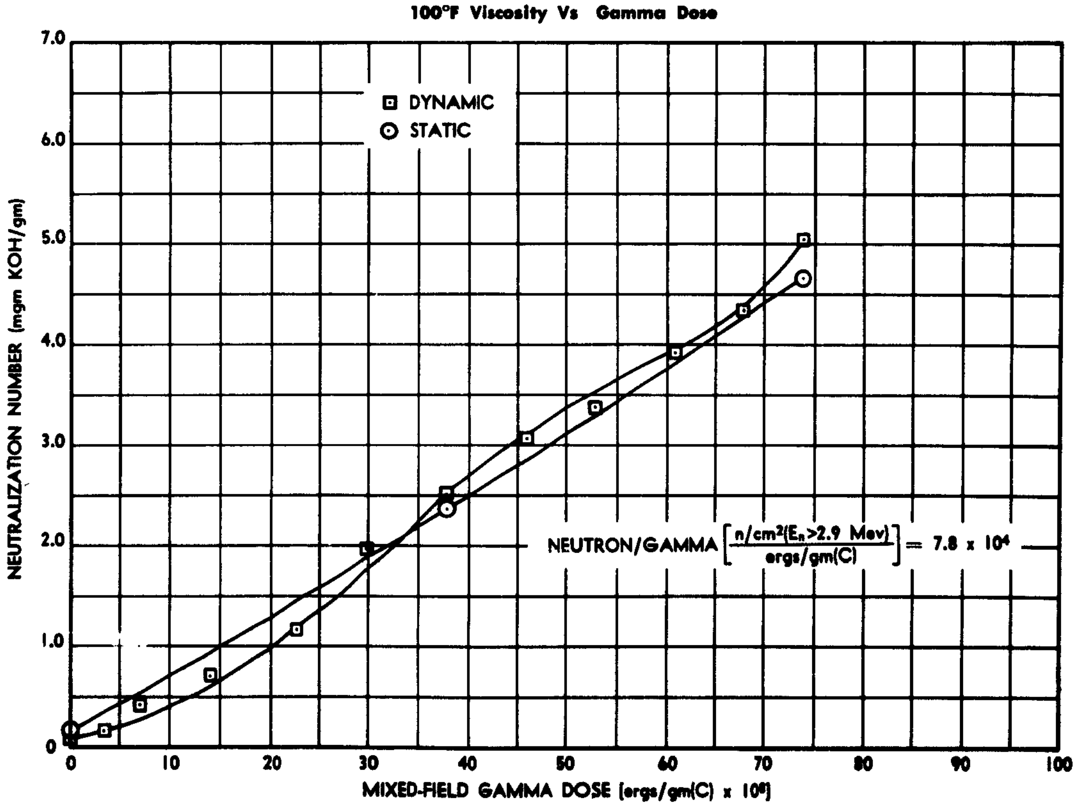
STATIC IRRADIATED AND DYNAMIC AND STATIC UNIRRADIATED DATA FOR GTO-790 *
(AVERAGE TEMPERATURE 300°F)

Preirradiation Dynamic Operation (hr)	12.5	25	37.5	50	0	0	0	0	0
Preirradiation Static Conditions (hr)	0	0	0	0	37.5	50	0	0	0
Static Irradiation (hr)	0	0	0	0	0	0	1	10	19.5
Average Gamma Dose [ergs/gm(C)]	0	0	0	0	0	0	3.4(8)	3.8(9)	7.4(9)
Average Integrated Neutron Flux (n/cm^2, $E_n > 2.9$ Mev)	0	0	0	0	0	0	3.0(13)	3.0(14)	5.8(14)
Viscosity (centistokes)									
@ -40°F	--	--	--	--	--	--	--	11,803	18,200
@ 100°F	28.07	28.34	29.16	29.13	27.74	27.77	28.28	31.19	36.33
@ 210°F	5.25	5.28	5.36	5.34	5.22	5.17	4.99	5.65	6.19
@ 400°F	--	--	--	1.33	--	1.33	--	1.44	1.56
Neutralization Number	0.24	0.55	0.92	1.23	0.14	0.19	0.12	2.36	4.68
Flash Point (°F)	480	470	--	465	--	465	445	450	405
Pour Point (°F)	--	--	--	-65	--	-85	--	-70	--
Evaporation Loss (% in 6-1/2 hr @ 400°F)	--	--	--	9.57	--	10.60	--	10.86	--
Coking Tendency									
Coke Formed @ 600°F (mg)	--	--	--	36.0	--	58.7	--	6.6	--
Oil Consumed @ 600°F (ml)	--	--	--	98.0	--	90	--	97.5	--
Lubricity (Shell Four-Ball Wear)									
1 hr @ 130°F, 1800 rpm									
Average Scar Diameter (mm): 20 kg Load	--	--	--	--	0.83	1.05	--	0.75	0.72
Average Scar Diameter (mm): 40 kg Load	--	--	--	--	0.92	1.22	--	0.88	0.96
Coefficient of Friction: 20 kg Load	--	--	--	--	.049	.055	--	0.063	0.057
Oxidation/Corrosion									
Weight Change (mg/cm^2)									
Copper	--	--	--	+0.03	--	+0.01	--	-3.55	-8.37
Steel	--	--	--	+0.08	--	+0.08	--	+0.05	+0.05
Silver	--	--	--	+0.09	--	+0.10	--	+0.03	+0.06
Aluminum	--	--	--	+0.07	--	+0.12	--	+0.05	+0.05
Magnesium	--	--	--	+0.11	--	+0.08	--	-5.11	-8.24
Appearance of Metal Specimens	--	--	--	Pass	--	Pass	--	Cu, Mg Fail	Cu, Mg Fail
% Viscosity Change (100°F)	--	--	--	+9.58	--	+16.10	--	+21.00	+33.77
Neutralization Number Change	--	--	--	-0.84	--	+0.31	--	-0.61	-1.61
Oxygen-Induction Period: Time to absorb 0.5 mole/500 gm @ 400°F (hr)	--	--	--	28.6	--	--	--	8.0	--

* See Table II for experimental conditions.



100°F Viscosity Vs Gamma Dose



Neutralization Number Vs Gamma Dose

FIGURE 10. DYNAMIC AND STATIC IRRADIATION OF GTO-790 OIL

the MIL-L-7808C specified maximum of 100 mgm. Coking panels are shown in Figure 11.

4.3 MIL-L-9236

The test data from the dynamic irradiation of MIL-L-9236 are listed in Table X. The static-irradiation data and data from the unirradiated control run are listed in Table XI. Differences due to static and dynamic irradiation were slight but evident (Fig. 12). Viscosity, neutralization number, and oxygen-absorption rate increased while flash point decreased. The tendency to form coke at 600°F and 700°F, shown in Figure 13, decreased during irradiation. However, coking tendency at both temperatures increased considerably during the preirradiation control run. This was true for both the static and dynamic samples, which indicates that the thermal stress (300°F for 20 hours) precipitated this increase in coking tendency. How this effect was offset by the irradiation is not evident, but it is assumed to have been the result of the loss of coke-forming constitutents through radiolytic gas evolution or the radiation-induced polymerization of these constituents into more thermally stable forms.

4.4 Gas Evolution Measurements

The straight lines in Figure 14 represent the slope of the gas evolution vs gamma-dose plot as determined by a least-squares analysis of the experimental data. Two runs

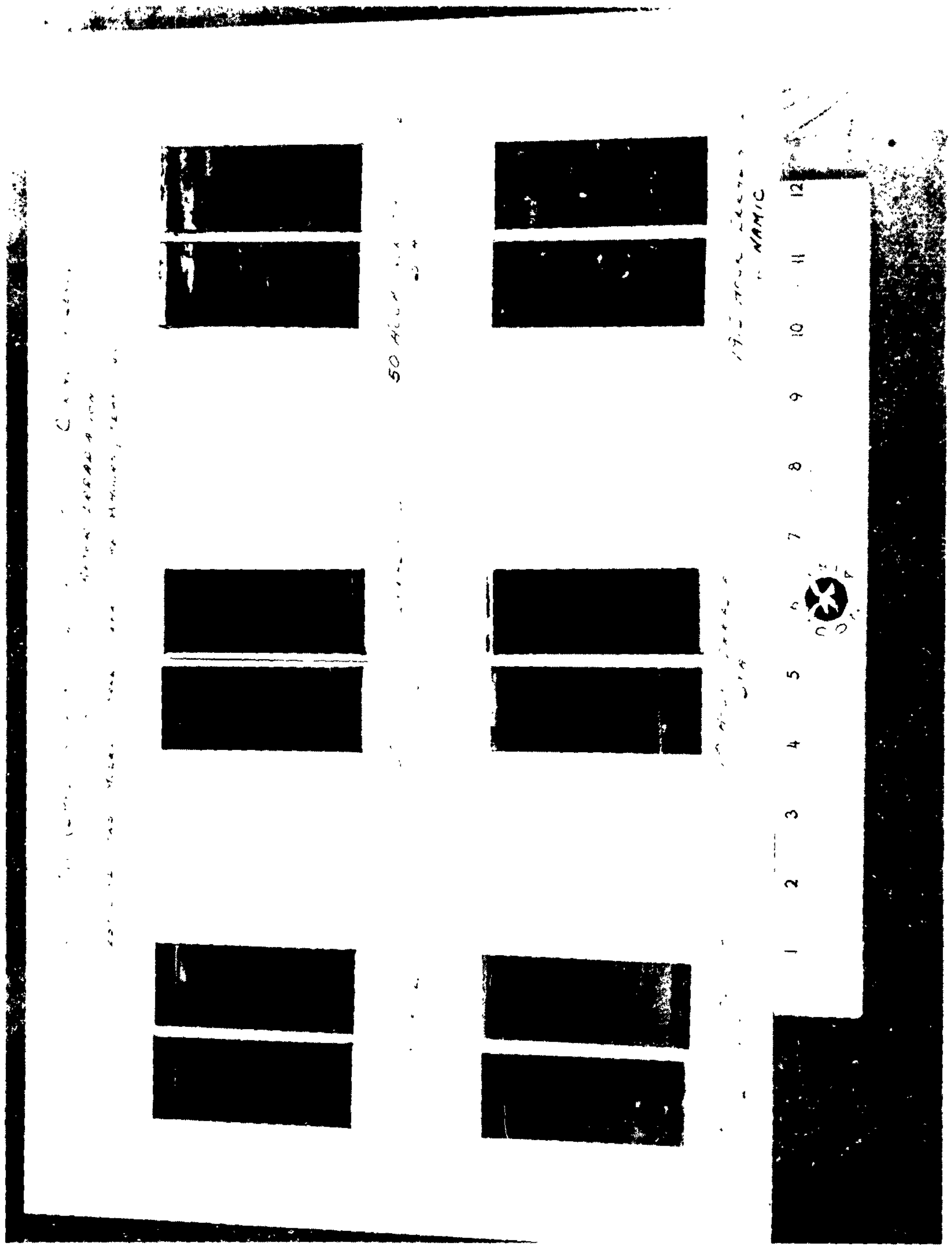


FIGURE 11. GTO-790 COKING PANELS

TABLE X

EFFECTS OF DYNAMIC IRRADIAT
(AVERAGE TEMPERATUR

Dynamic Irradiation (hr)	0	1	2	4	6	8
Average Gamma Dose [ergs/gm(C)]	--	4.6(8)	9.2(8)	1.8(9)	2.8(9)	3
Average Integrated Neutron Flux (n/cm^2, $E_n > 2.9$ Mev)	--	2.75(13)	5.5(13)	[illegible].10(14)	1.65(14)	2
Viscosity (centistokes)						
@ 100°F	15.96	16.46	16.67	16.78	17.59	18
@ 210°F	3.57	3.66	3.66	3.69	3.86	3
@ 400°F	1.07	--	--	--	--	
Neutralization Number	0.02	0.45	0.85	0.90	2.24	3
Flash Point (°F)	465	465	470	465	440	435
Fire Point (°F)	510	515	510	515	500	505
Pour Point (°F)	-90	--	--	--	--	
Evaporation Loss (% @ 400°F)	15.03	--	--	--	--	
Coking Tendency						
Coke Formed @ 600°F (mg)	33.90	--	--	--	--	
Coke Formed @ 700°F (mg)	127.35	--	--	--	--	
Oil Consumed @ 600°F (ml)	168	--	--	--	--	
Oil Consumed @ 700°F (ml)	428	--	--	--	--	
Lubricity (Shell Four-Ball Wear)						
1 hr @ 130°F, 1800 rpm						
Average Scar Diameter (mm): 20 kg Load	0.686	--	--	--	--	
Average Scar Diameter (mm): 40 kg Load	0.725	--	--	--	--	
Coefficient of Friction: 20 kg Load	0.089	--	--	--	--	
1 hr @ 400°F, 1800 rpm						
Average Scar Diameter (mm): 20 kg Load	0.818	--	--	--	--	
Average Scar Diameter (mm): 40 kg Load	1.055	--	--	--	--	
Coefficient of Friction: 20 kg Load	0.082	--	--	--	--	
Oxygen-Induction Period: Time to absorb 0.5 mole/500 gm @ 400°F (hr)	71	--	16	--	8.50	

*See Table II for experimental conditions.

TABLE X

YNAMIC IRRADIATION ON MIL-L-9236B *
RAGE TEMPERATURE 300°F)

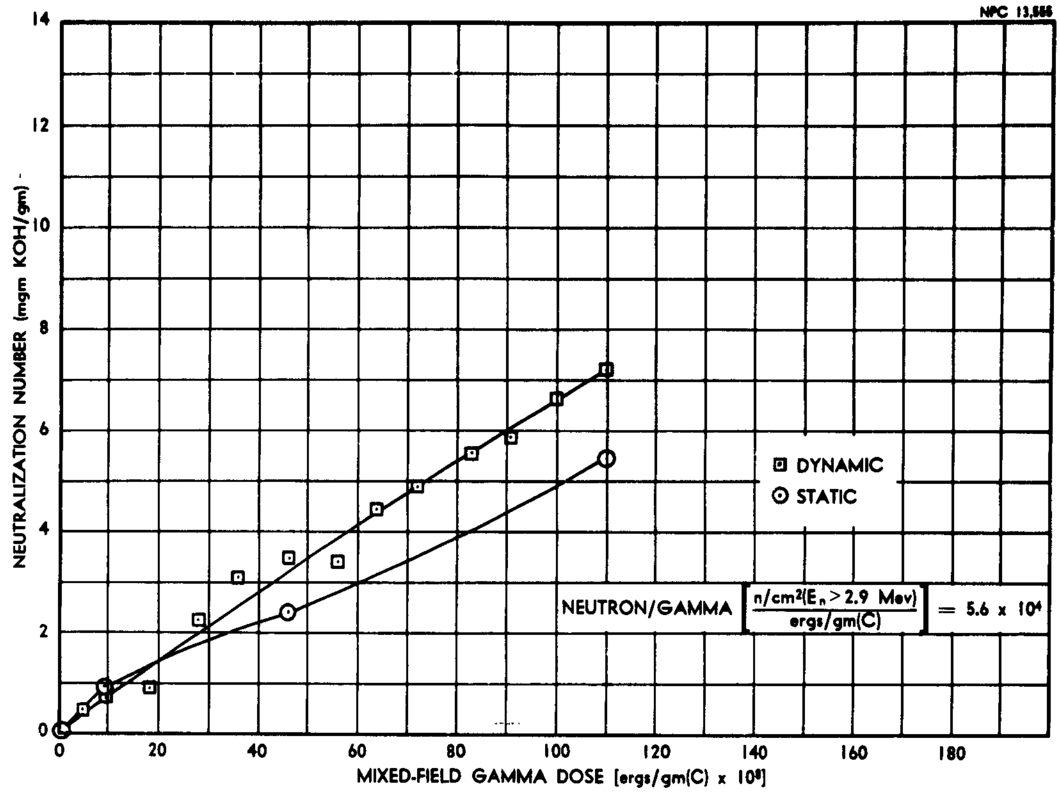
6	8	10	12	14	16	18	20	22	23
2.8(9)	3.6(9)	4.6(9)	5.6(9)	6.4(9)	7.2(9)	8.3(9)	9.1(9)	1.0(10)	1.1(10)
1.65(14)	2.20(14)	2.75(14)	3.30(14)	3.83(14)	4.40(14)	5.0(14)	5.5(14)	6.0(14)	6.3(14)
17.59	18.53	18.29	18.44	19.17	19.50	20.08	20.59	21.05	21.27
3.86	3.93	3.97	4.00	4.06	4.11	4.19	4.26	4.27	4.37
--	--	1.13	--	--	--	--	--	--	1.28
2.24	3.10	3.47	3.42	4.48	4.90	5.59	5.88	6.63	7.25
440	435	445	440	435	440	440	415	385	375
500	505	505	500	495	495	495	500	495	485
--	--	-85	--	--	--	--	--	--	-85
--	--	19.44	--	--	--	--	--	--	20.52
--	--	5.10	--	--	--	--	--	--	6.60
--	--	22.1	--	--	--	--	--	--	23.70
--	--	190	--	--	--	--	--	--	197.50
--	--	485	--	--	--	--	--	--	482.50
--	--	0.883	--	--	--	--	--	--	0.769
--	--	1.170	--	--	--	--	--	--	0.851
--	--	0.048	--	--	--	--	--	--	0.040
--	--	1.05	--	--	--	--	--	--	1.240
--	--	1.40	--	--	--	--	--	--	1.620
--	--	0.073	--	--	--	--	--	--	0.075
8.50	--	5.30	--	5.6	--	4.0	--	--	4

TABLE XI

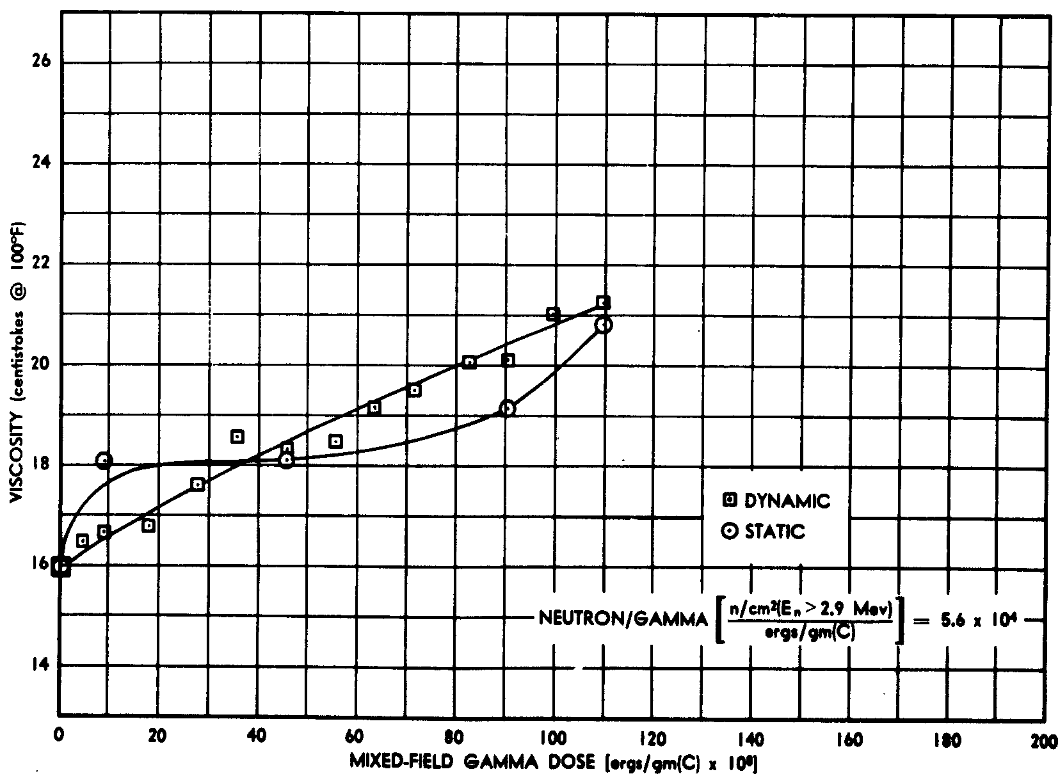
STATIC IRRADIATED AND DYNAMIC AND STATIC UNIRRADIATED DATA FOR MIL-L-9236 *
(AVERAGE TEMPERATURE 300°F)

Preirradiation Dynamic Operation (hr)	5	10	15	20	0	0	0	0	0
Preirradiation Static Conditions (hr)	0	0	0	0	20	0	0	0	0
Static Irradiation (hr)	0	0	0	0	0	2	10	20	23
Average Gamma Dose [ergs/gm(C)]	--	--	--	--	--	9.2(8)	4.6(9)	9.1(9)	1.1(10)
Average Integrated Neutron Flux (n/cm^2, $E_n > 2.9$ Mev	--	--	--	--	--	5.5(13)	2.75(14)	5.5(14)	6.3(14)
Kinematic Viscosity (centistokes)									
@ 100°F	16.34	16.25	16.41	16.33	15.59	18.07	18.17	19.19	20.82
@ 210°F	3.60	3.63	3.64	3.58	3.63	3.88	3.91	4.11	4.34
@ 400°F	--	--	--	1.17	1.26	--	1.14	--	1.36
Neutralization Number	0.11	0.13	0.16	0.16	0.42	0.93	2.39	4.49	5.48
Flash Point (°F)	455	470	490	475	455	460	455	460	430
Fire Point (°F)	--	--	--	515	515	505	510	510	495
Pour point (°F)	--	--	--	-90	-90	--	-80	--	-75
Evaporation Loss (% @ 400°F)	--	--	--	16.18	16.60	--	24.79	--	21.28
Coking Tendency									
Coke Formed @ 600°F (mg)	--	--	--	40.7	97.6	--	16.0	Ins. Sample	Ins. Sample
Coke Formed @ 700°F (mg)	--	--	--	295.55	290.3	--	46.4		27.0
Oil Consumed @ 600°F (ml)	--	--	--	175	170	--	185		
Oil Consumed @ 700°F (ml)	--	--	--	425	500	--	435		475
Lubricity (Shell Four-Ball Wear)									
1 hr @ 130°F, 1800 rpm									
Average Scar Diameter (mm): 20 kg Load	--	--	--	0.870	0.750	--	0.783	--	0.769
Average Scar Diameter (mm): 40 kg Load	--	--	--	0.942	0.844	--	0.864	--	0.846
Coefficient of Friction: 20 kg Load	--	--	--	0.066	0.055	--	0.054	--	0.052
1 hr @ 400°F, 1800 rpm									
Average Scar Diameter (mm): 20 kg Load	--	--	--	0.899	0.792	--	0.588	--	0.646
Average Scar Diameter (mm): 40 kg Load	--	--	--	1.16	1.08	--	0.924	--	1.020
Coefficient of Friction: 20 kg Load	--	--	--	0.079	0.078	--	0.073	--	0.062
Oxygen-Induction Period: Time to absorb 0.5 mole/500 gm @ 400°F (hr)	--	--	--	--	--	14.7	9.0	--	5.5

* See Table II for experimental conditions.



Neutralization Number Vs Gamma Dose



100°F Viscosity Vs Gamma Dose

FIGURE 12. DYNAMIC AND STATIC IRRADIATION OF MIL-L-9236 OIL

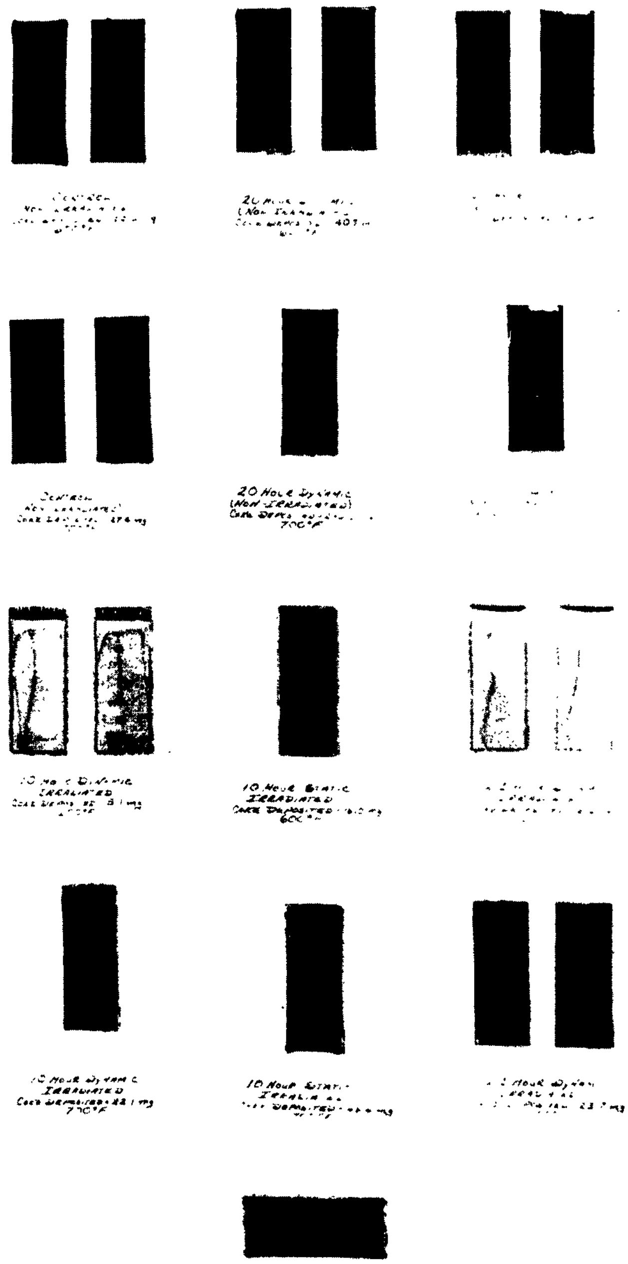


FIGURE 13. MIL-L-9236 COKING PANELS

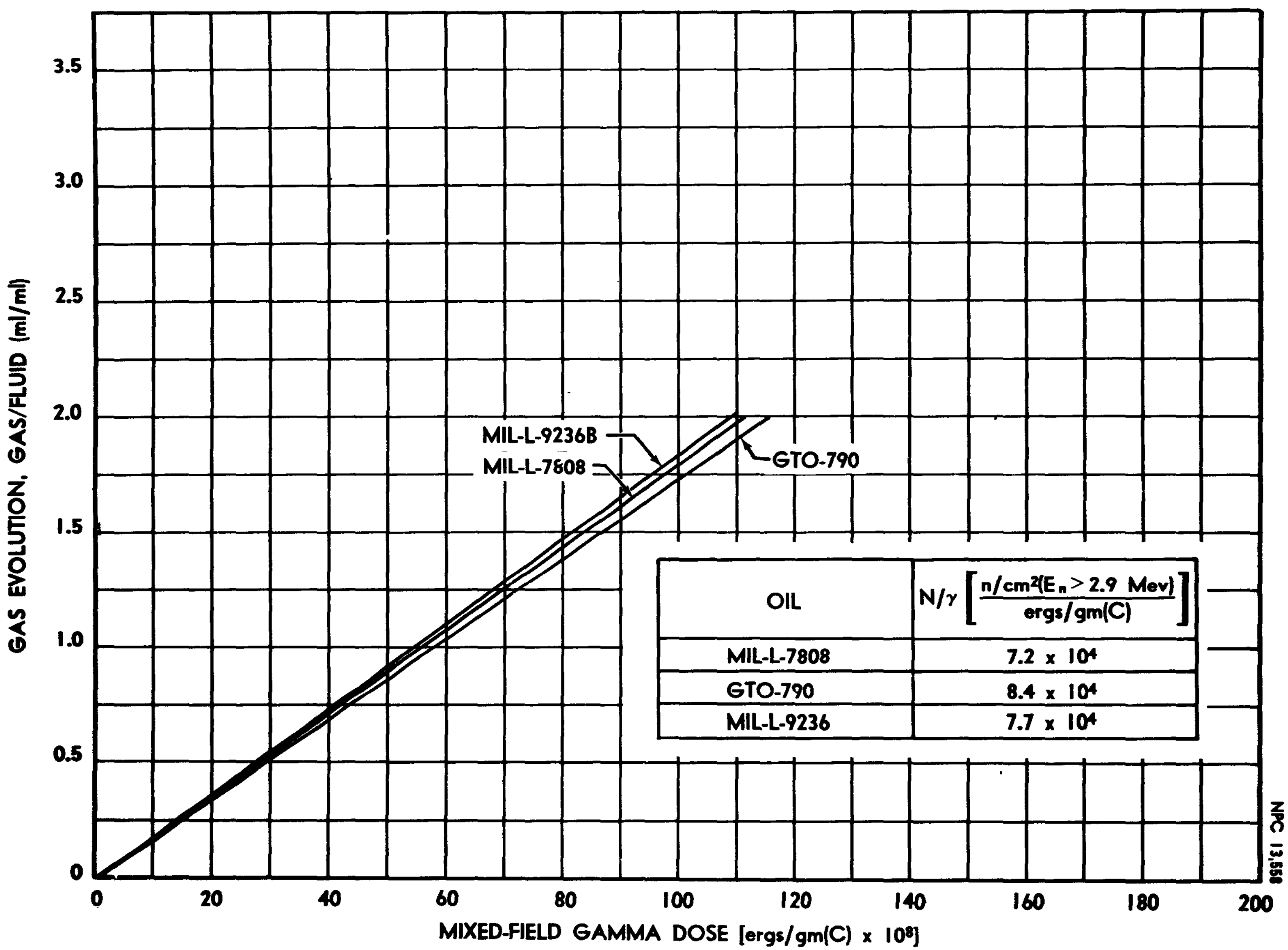


FIGURE 14. GAS EVOLUTION VS GAMMA DOSE FOR THREE OILS

were made on MIL-L-7808C at slightly different dose rates. The data from the two runs are in very good agreement. Only one run was made on each of the other two oils.

Quantitative gas evolution was very similar for the three oils. The data indicate the following amounts of gas evolution from the fluids if each were exposed to 1×10^{10} ergs/gm(C) in a reactor field:

MIL-L-7808C - 1.81 ml of gas per ml of fluid

GTO-790 - 1.73 ml of gas per ml of fluid

MIL-L-9236B - 1.84 ml of gas per ml of fluid

The 95% confidence interval for a single predicted value calculated from the two MIL-L-7808C runs was ±0.088 ml of gas per ml of fluid.

4.5 Comparison of MIL-L-7808C, GTO-790, and MIL-L-9236B

As indicated in Section 3.1 the irradiation rate, temperature, and sampling schedule were very similar for MIL-L-7808C (Run 3), the GTO-790 run, and the MIL-L-9236B run. The data from these three runs, therefore, provide a basis for comparing the radiation resistance of three oil types. With respect to the particular conditions listed for these irradiations, the relative results from the three experiments may be summarized as follows:

a. Each of the three oils completed the control runs at 300°F with no significant loss in properties or damage to the Dynamic Test Loop.

b. Each of the three oils completed the irradiation without significant damage to the Dynamic Test Loop.

c. Lubricating properties, as measured by the Shell Four-Ball Wear Test, indicated smaller scar diameters for MIL-L-7808C both before and after irradiation. Scar diameters were similar for GTO-790 and MIL-L-9236, with none of the oils showing any appreciable loss of lubricity due to irradiation. Table XII shows this comparison for the dynamic samples.

d. Changes in the tendency to form coke were much more pronounced in MIL-L-7808 than in GTO-790 or MIL-L-9236. Some increase in coking was evident in GTO-790, with MIL-L-9236 showing a decrease. Coking data for the three dynamic irradiations are also listed in Table XII.

e. MIL-L-7808 showed a much larger increase in neutralization number than GTO-790 or MIL-L-9236. All three oils, however, suffered very large increases in this property. No appreciable difference was observed between increases in neutralization number in GTO-790 and MIL-L-9236. Figure 15A shows the changes in neutralization number for the three oils.

f. The oxygen-absorption-rate tests on unirradiated MIL-L-7808 indicated that this oil had less oxidation resistance at 400°F than either GTO-790 or MIL-L-9236. The tests on irradiated MIL-L-7808C, however, did not show the large increase in oxygen-absorption rate seen in the other two oils. These data appear contradictory to the other property measurements, which indicate more degradation to MIL-L-7808. This behavior cannot be logically explained on the basis of the present data alone. The changes in oxygen-induction period for the three oils are also shown in Figure 15A.

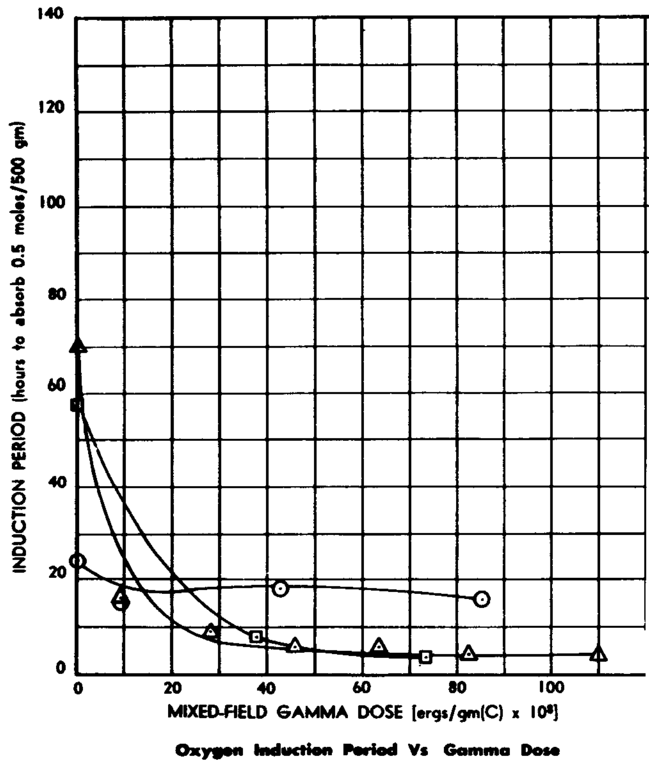
g. Figure 15B shows the changes in 210°F viscosity for the three oils. GTO-790 and MIL-L-9236 increased in viscosity throughout the irradiation, while MIL-L-7808 decreased sharply and then showed an increase. Although the loss of viscosity did not cause the MIL-L-7808 to fall

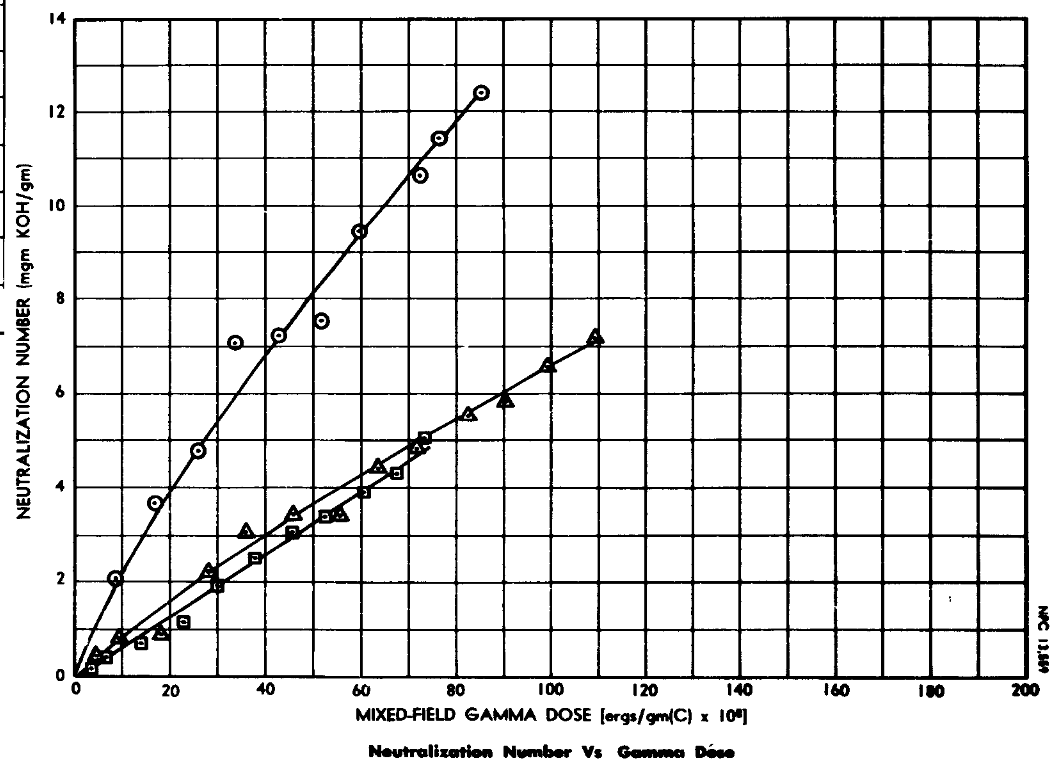
TABLE XII

EFFECTS OF DYNAMIC IRRADIATION ON THE SHELL FOUR-BALL WEAR PROPERTIES AND COKING TENDENCY OF THREE OILS

Lubricant	Gamma Dose [ergs/gm(C)]	Integrated Neutron Flux (n/cm^2)*	Wear Scar Diameter (mm)**		600°F		700°F	
			20-kgm Load	40-kgm Load	Coke	Oil Used	Coke	Oil Used
MIL-L-7808C, Run 3	0	0	0.29	0.45	9	187	-	-
	4.3×10^9	2.6×10^{14}	0.35	0.45	545	200	-	-
	8.6×10^9	5.1×10^{14}	0.32	0.57	1635	200	-	-
GTO-790	0	0	0.96	1.04	30	95	-	-
	3.8×10^9	3.0×10^{14}	0.70	1.01	4	95	-	-
	7.4×10^9	5.8×10^{14}	0.72	1.00	119	100	-	-
MIL-L-9236 (GTO-915)	0	0	0.69	0.73	34	168	127	428
	4.6×10^9	2.8×10^{14}	0.88	1.17	5	190	22	485
	1.1×10^{10}	6.3×10^{14}	0.77	0.85	7	198	24	483

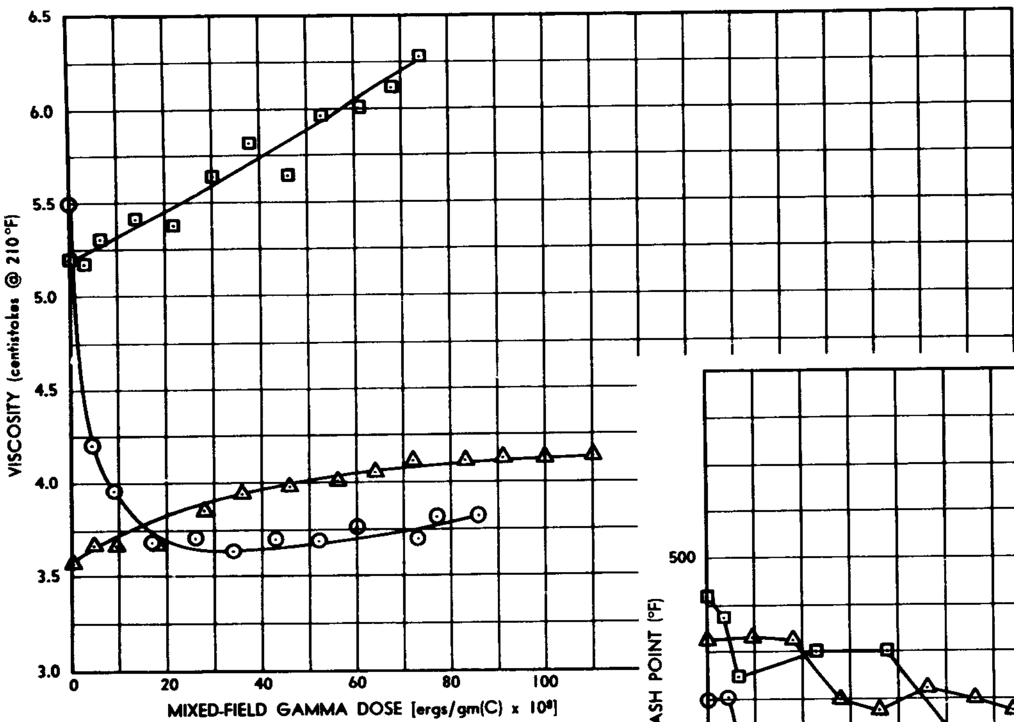
* $E_n > 2.9$ Mev
** 130°F, 1800 rpm





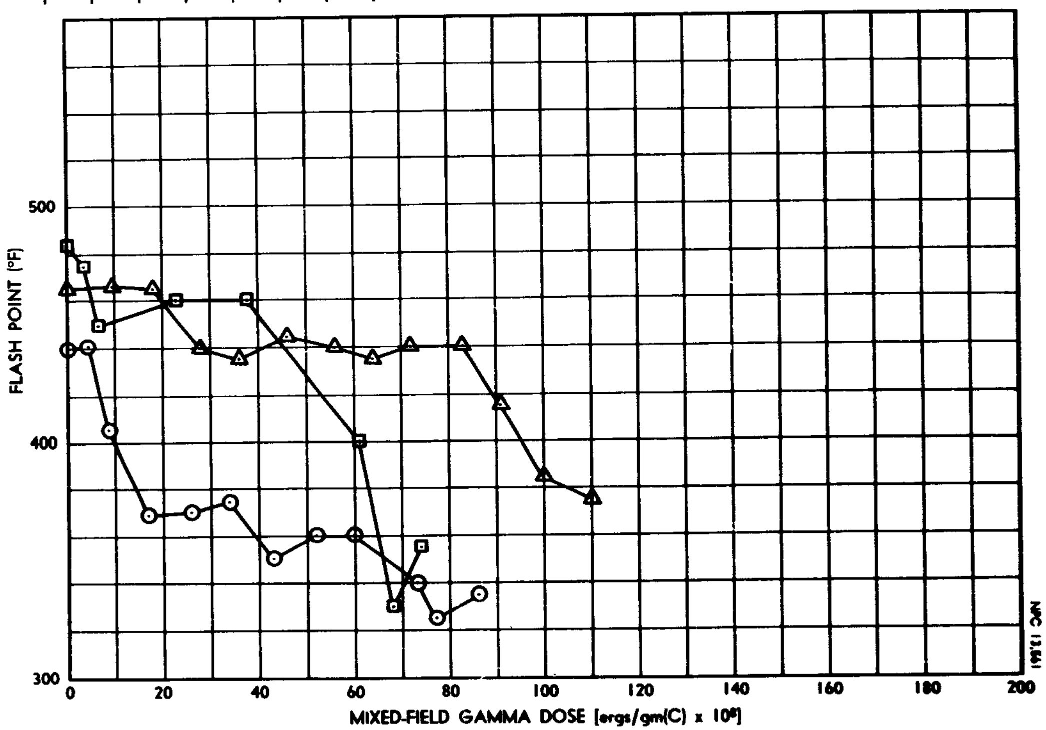
OIL	$N/\gamma \left[\frac{n/cm^2(E_n > 2.9\ Mev)}{ergs/gm(C)}\right]$
⊙ MIL-L-7808C, RUN 3	5.9×10^4
⊡ GTO-790	7.8×10^4
△ MIL-L-9236	5.6×10^4

FIGURE 15 A. EFFECTS OF DYNAMIC IRRADIATION ON THREE OILS



210°F Viscosity Vs Gamma Dose

OIL	N/γ $\left[\frac{n/cm^2(E_n > 2.9\ Mev)}{ergs/gm(C)}\right]$
⊙ MIL-L-7808, RUN 3	5.9×10^4
⊡ GTO-790	7.8×10^4
△ MIL-L-9236	5.6×10^4



Flash Point Vs Gamma Dose

FIGURE 15 B. EFFECTS OF DYNAMIC IRRADIATION ON THREE OILS

below the specification minimum, it nevertheless would probably decrease the load-carrying ability of the oil. Load-carrying ability, however, was not checked on the samples because of a lack of equipment.

h. The three oils each suffered large decreases in flash point, with MIL-L-9236 maintaining a somewhat higher and more constant flash point. This property, however, showed the typical irregular change throughout the irradiation on each oil. Figure 15B shows the flash point changes.

i. The results of the separate gas-evolution experiments indicate that a similar quantity of gas will be liberated from each of the three oils when similar radiation conditions are imposed.

V. CONCLUSIONS

The following general conclusions represent the author's overall interpretation of the data obtained in the experimental work covered by this report:

- MIL-L-7808C, GTO-790, and MIL-L-9236B were not appreciably damaged by running in the Dynamic Test Loop at 300°F in the absence of radiation.

- Each of the oils irradiated suffered extensive loss of important properties during irradiation at 300°F under both static and dynamic conditions.

- MIL-L-7808C was more sensitive with regard to radiation-induced property changes than GTO-790 or MIL-L-9236B under the conditions of these experiments. The larger increases in coking tendency and neutralization number form the basis for this conclusion.

- No great difference was detected between the effects of radiation on GTO-790 and MIL-L-9236B (GTO-915) under the conditions imposed.

- Radiation damage to the properties of MIL-L-7808C was partially dependent on the rate at which radiation dose was accrued. More damage resulted from a given total dose as dose rate was decreased.

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(NARF-61-22T; MR-N-281)
(Contract AF 33(657)-7201) Unclassified report

Samples of three aircraft turbine lubricating oils were irradiated with the Ground Test Reactor at General Dynamics/Fort Worth while being worked in a special Dynamic Test Loop; static (unworked) samples were included in each irradiation.

MIL-L-7808C was irradiated at three exposure levels ranging from 4.6×10^6 to 2.0×10^9 ergs/gm(C)-hr gammas and 6.1×10^9 to 3.3×10^{10} n/cm^2-sec ($E_n > 2.9$ Mev) neutrons; GTO-790 was irradiated at a gamma dose rate of 3.4×10^8 ergs/gm(C)-hr and 8.3×10^9 n/cm^2-sec ($E_n > 2.9$ Mev) associated neutrons;
(over)

1. Airplane Engine Oils - Effects of Radiation
I. Haley, F. A.

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Nuclear Aerospace Research Facility, General Dynamics/Fort Worth, Fort Worth, Texas.
EFFECTS OF MIXED-FIELD RADIATION ON TURBINE LUBRICATING OILS, by F. A. Haley. November 1961. 61p. incl. illus. tables, 14 refs.
(NARF-61-22T; MR-N-281)
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MIL-L-9236B was irradiated at a gamma dcse rate of 4.6×10^8 ergs/gm(C)-hr and 1.1×10^{10} n/cm^2-sec ($E_n > 2.9$ Mev) associated neutrons. Bulk-oil temperatures ranged from 275° to 300°F during irradiation.

The results of property and performance measurements made on samples withdrawn during each irradiation indicate that MIL-L-7808C is somewhat more sensitive to reactor radiation than GTO-790 or MIL-L-9236B, both of which exhibited a similar resistance to radiation. Some variations were also noted between worked and unworked samples of each oil.

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